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DECEMBER 2022
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Take the mess out of prototyping new designs

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Building the amplifiers and Active Crossover

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An ARM-based module for wireless communication

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Generate an adjustable voltage while multi-tasking

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By Dr David Maddison ***Space exploration feature***

48 Jaycar QC1938 Oscilloscope

Jaycar's QC1938 two-channel, 100MHz digital oscilloscope was released just a few months ago, with many handy features at a low cost.

By Tim Blythman ***Test equipment review***

76 nRF5340 DK Development Board

Nordic Semiconductor's nRF5340 DK is a development board with a dual-core ARM chip. It's Arduino-compatible and is a good starting point for designing products with Bluetooth, NFC or other wireless communications.

By Tim Blythman ***Microcontroller module review***

31 Dual-channel Breadboard PSU

This power supply is designed to help you take the mess out when prototyping new designs on a breadboard. It plugs straight into a breadboard's power rails and has two adjustable current-limited outputs.

By Tim Blythman ***Power supply project***

40 Breadboard PSU Display Adaptor

Combine the Breadboard PSU from above with this Display Adaptor to show lots of handy data, such as the set and actual voltages and currents. It even includes extra voltmeter and ammeter channels for analysis.

By Tim Blythman ***Power supply project***

62 Active Monitor Speakers, Part 2

This month, we cover how to build the power supply, prepare the chassis and arrange the wiring for the Active Crossover Amplifier. Plus, there's a section to help troubleshoot most problems that could occur.

By Phil Prosser ***Audio project***

81 Digital Boost Regulator

The multi-tasking Digital Boost Regulator can generate an adjustable voltage from 5V to 20V without a dedicated boost chip. This is possible due to its use of a PIC16F1846 microcontroller.

By Tim Blythman ***Microcontroller project***

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Editorial Viewpoint

Circuit labelling consistency

There are many valid, logical schemes for labelling components on circuit diagrams and PCBs, but we need to stick to one system. It would be very confusing for different designs in the same issue (or subsequent issues) to use the same letters for different purposes.

As SILICON CHIP was started by ex-EA staff, the labelling scheme we use is derived from that of EA but with changes that they considered improvements. For example, in EA, transistors were generally labelled as "TR" followed by a number, but we use "Q" followed by a number. That might only save one letter, but any space saved is helpful on a cluttered circuit or PCB.

The problem we have is that we often receive circuit submissions from contributors that use different schemes. Not only are their schemes different from ours, but they are also different from each other. There are many pitfalls in changing their labels to match ours, such as the possibility for mistakes to creep in.

It is also difficult for us to change the silkscreen labelling on submitted PCBs because we don't necessarily have the required software. We can modify files that can be opened by Altium Designer or Eagle (and possibly other free packages like KiCad). But it is time-consuming to modify PCB files produced by other packages.

Due to this, I would like to ask anyone considering sending us a circuit or design to either use the same scheme we do, or modify your ECAD files before submitting them to match our scheme. That way, we minimise the chance of errors and can ensure that readers and constructors can figure out which components are which.

It is not unknown for the labels on PCBs we supply to have mismatches with the information published for this reason. At times, that has caused considerable confusion, so I'm hoping we can avoid that in future.

I can't list our entire scheme here (you can always e-mail us and ask) but briefly, here are the common designator prefixes we use:

Resistor: **R**	Capacitor: **C**	Inductor: **L**
Switch or button: **S**	Fuse: **F**	Bridge rectifier: **BR**
Diode: **D**	Zener diode: **ZD**	LED: **LED**
Transistor: **Q**	Crystal/resonator: **X**	Integrated circuit: **IC**
Transformer: **T**	Relay: **RLY**	Potentiometer: **VR**
Optocoupler: **OPTO**	Regulator: **REG**	Voltage reference: **REF**
Receiver: **RX**	Transmitter: **TX**	Battery/Cell: **BAT**
Thermistor: **NTC/PTC**	Link: **LK** (on/off) or **JP** (multiple options)	
Modules: **MOD**	Antenna: **ANT**	Test point: **TP**
Infrared receiver: **IR**	Connector (header or other): **CON**	

Postage cost increase

We have been charging the same $10 per order for postage and packing in our Online Shop for around 13 years (since 2009). The costs of postage, packing and labour have all increased significantly since then (by around 30%). So, from January 1st 2023, our P&P prices will be:

- *Regular Post within Australia: $12 (was $10)*
- *Guaranteed tracking within Australia: from $14 (was $12)*
- *Express Post within Australia: from $16 (was $15)*

It isn't all bad news; these days, you're far more likely to get a tracking number even if you pay the lowest postage cost (but it is only guaranteed if you choose one of the tracked options). Overseas postage depends on the size and weight of the order; you can get a quote via our website. ***Note that our PO Box address has changed, we plan to keep the old address for a few months.***

Cover image: NGC 3324 inside Carina Nebula
NASA, ESA, CSA and STScI

by Nicholas Vinen

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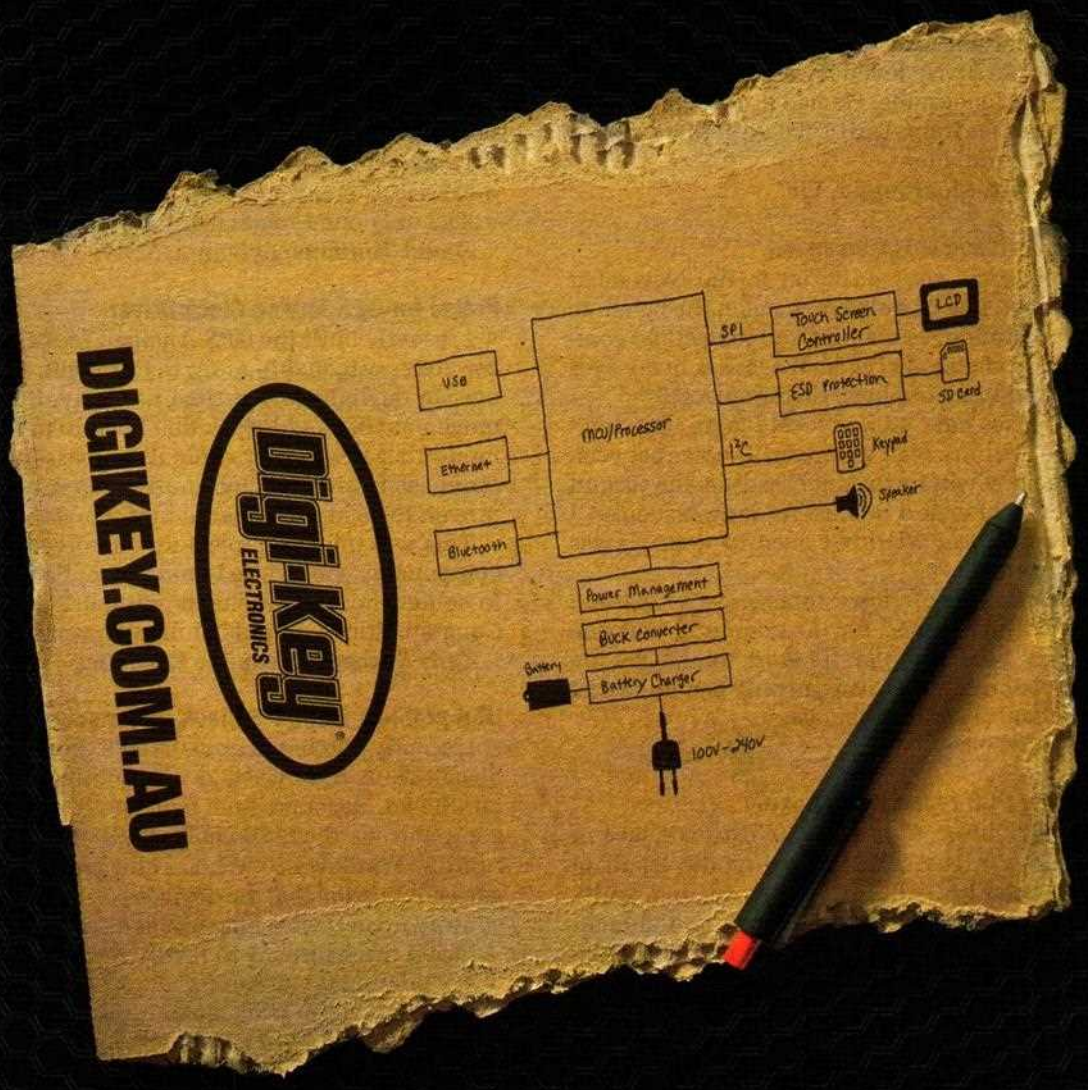

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RIP Rodney Champness

My husband, Rodney Champness, passed away on the 22nd of October, 2022. He loved writing articles on Vintage Radio for your magazine. He had articles published in most of your issues from April 1998 until March 2013, with a few before and after.

Lynn Champness, Mooroopna, Vic.

Response to Editorial on close-up vision

I read with interest your Editorial in the November issue. In my career, I went from working on the bench to management and found, as you did, too long at the computer changed my vision. As I aged, the lenses in my eyes became cloudy and I had to have them replaced.

As the new lenses have a fixed focal length that don't change with the eye muscles, I was given a choice between three types. The first was focused for reading, the second for watching television and the last for long distances. I selected the second as I wouldn't need to wear glasses around the house.

This result is that I now have three pairs of glasses: one for close work, a second for the computer and one for long distance. I still find that if I work too long at the computer, my vision changes, so I can only conclude that it is the brain that causes this change.

Les Kerr, Ashby, NSW.

Caution regarding PCB repair with epoxy

I saw the contribution from N.B., in Taylors Lakes in Serviceman's Log, August 2022, regarding the repair of a PCB that had been badly burnt, I guess due to a faulty relay. I was quite impressed with the repair and thought he did an excellent job. However, at the risk of sounding like Chicken Little, I feel obliged to point out a couple of things:

1. That board is UL listed (the RU mark can be clearly seen) and is made from 94V-0 material (also clearly marked). 94V-0 is made to be fire resistant; I believe it is expected to self-extinguish a fire. I'm not sure your garden variety Araldite would pass this test. Looking at the PCB before the repair, you can see why the PCB has to be rated like this – fire is a real possibility.

2. Relay contacts can generate a fair amount of heat even when not faulty – in my experience, more than you expect. The PCB copper is used to dissipate heat from the contacts – the repair that was made is likely poorer than the original PCB in this regard. An insulated wire is much worse as a heatsink than a broad, exposed copper track

The upshot is that the relay may fail again sooner than expected and, scarily, cause a fire.

Finally, you sometimes mention SMD resistor codes in your articles; eg, a 1kΩ resistor might be marked 102 or 1001. But there is another common method of resistor marking I've come across. This 'standard' uses two digits and a letter; Google "EIA-96". I used to see it quite a lot – not so much these days, but working from home, I don't see as many completed PCBs.

The only one I remember is "01C" = 10kΩ.

David Timmins, Sylvania, NSW.

Praise for GPS Analog Clock Driver

I recently built the GPS Analog Clock Driver (September 2022; siliconchip.au/Article/15466), and it switched over to daylight saving time perfectly. I dismantled the movement of an old clock that I had in my workshop but found that it was very difficult to reassemble. Instead, I purchased a simpler clock movement from Jaycar, which proved to be much easier to incorporate into the project.

This was my first project that involved surface mount components and, while I found it challenging, I was able to solder those components without too much trouble. Congratulations on publishing this very useful project.

Tony Verberne, Ivanhoe East, Vic.

USB problem with GPS Clock Driver solved

I recently purchased from the GPS Clock Driver kits from Silicon Chip (Cat SC6472). Everything works exactly as per the article, apart from being able to connect it to my computer via the USB cable. Both of my computers are running Windows 10. When I plugged in the USB cable, I got a notification that the device was not recognised, and it showed up in Device Manager as an unrecognised device.

I tried the following to rectify the problem:

- Updating the drivers
- Changing the USB cable
- Using a different computer

I finally found the problem, and yes, it was my fault! I managed to get a very small solder bridge between pins 2 and 3 on the USB socket. A dab of flux and a hot iron fixed the problem immediately.

Alfred Hirzel, Auckland, NZ.

Disposing of unwanted equipment via ARNSW

Firstly, keep up the good work producing an excellent magazine; I look forward to reading each issue.

I have seen a couple of letters to the editor about disposing of equipment as people are downsizing. I am the equipment sales contact for Amateur Radio NSW. Part of the club's activities is to hold a sales event every two months.

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There are three ways that the club can help with equipment disposal. One is for the owner to sell directly on the day to 50 to 80 buyers, the club can sell equipment for a small commission, or equipment can be donated to the club.

The type of equipment the club sells includes amateur radio equipment, communications equipment (receivers and transceivers), test equipment, military electronics and vintage domestic radios. Components and valves are included. We do not handle computer equipment (PCs, laptops, monitors etc), domestic electronics such as TVs and audio equipment, or large/heavy equipment.

For further information, including contact details, please visit the club's website at arnsw.org.au

Mark Blackmore, Baulkham Hills, NSW.

Uploading WiFi Load firmware when OTA fails

I have had some difficulty uploading software to the control board for the WiFi DC Load project (September & October 2022; siliconchip.au/Series/388). Following the article's instructions, I can upload the file "DC_Load_3-5.ino.bin" over-the-air (OTA), and the application starts up and functions as it should, detecting all hardware and connecting to my WiFi.

However, when I disconnect and reconnect power to the ESP32 board, it reverts to running the OTAWebUpdater application, and the DC Load software seems to have vanished. This process is 100% repeatable.

I tried the same uploading process to a different ESP32 board with the same outcome. I also tried two different versions of the Arduino IDE, 1.8.19 and 2.0.0. No matter what I did, I could not get the DC_Load program to stick in the ESP32 board when uploading via OTA. However, uploading via the serial port worked.

Richard Palmer helped me compile the code myself in the Arduino IDE so I could directly upload it to the ESP32 board. It is now correctly retained in the ESP32 module. In case anyone else runs into the same problem, I thought I'd provide some advice on doing that. The main difficulty is in downloading and installing all the required libraries to build the code. They are:

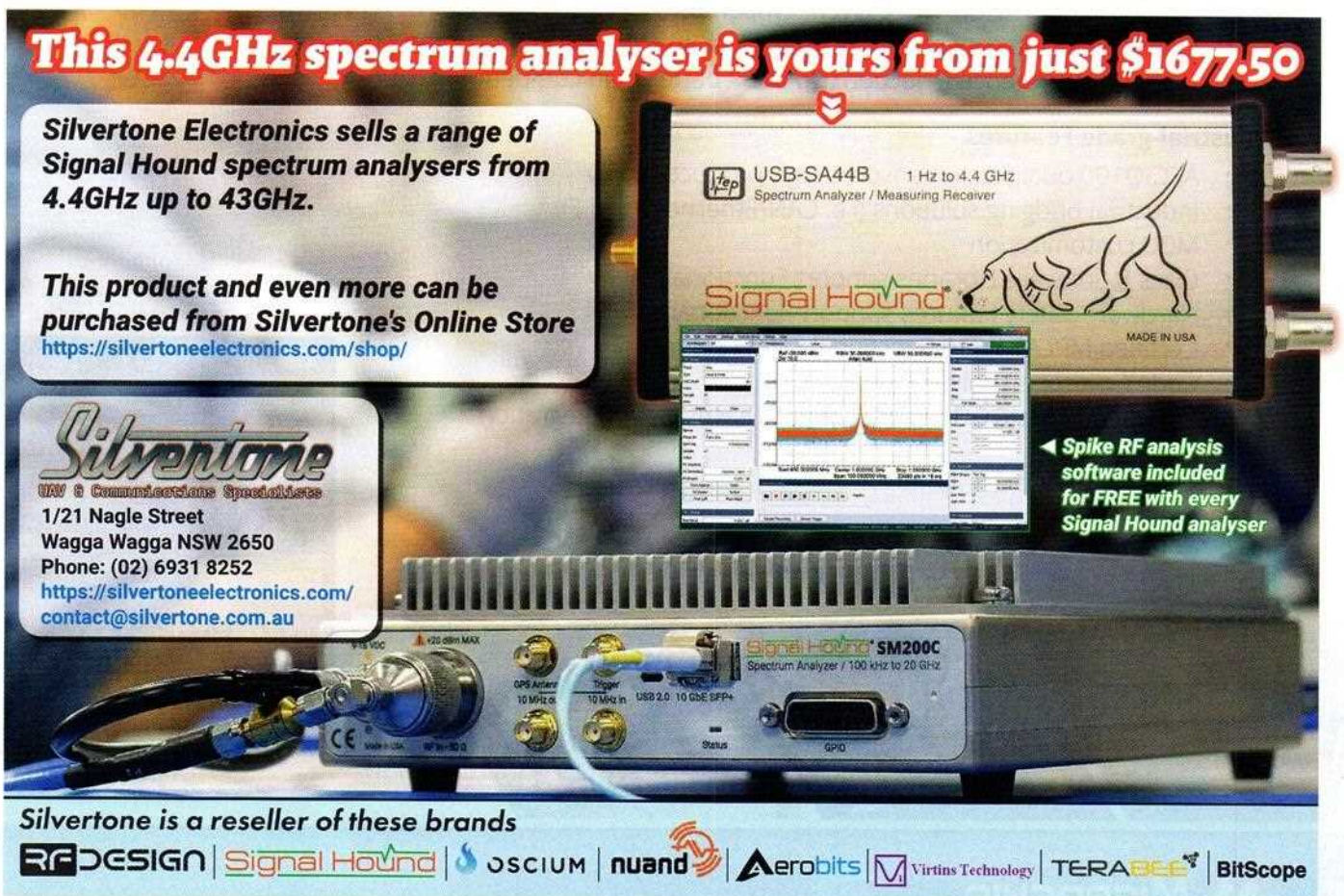
- Adafruit GFX (1.11.13)
- Arduino_GFX (1.3.0)
- XPT2046_Touchscreen (1.4.0)
- ArduinoJson (6.19.4)
- ESP32Encoder (V0.9.1)
- Button2 (2.0.3)
- https://github.com/me-no-dev/ESPAsyncWebServer
- https://github.com/me-no-dev/AsyncTCP
- Adafruit_ILI9488 – modified from Adafruit_ILI9341 library by Richard Palmer

Based on what Richard told me, the problem might be that different ESP32 modules have different memory sizes, and mine possibly doesn't have enough memory to flash the large DC Load program via the OTA method. But it seems it can be flashed via USB using the Arduino IDE.

Erwin Bejsta, Wodonga, Vic.

Recollections of an unusual vintage ohmmeter

The Wide Range Ohmmeter (August & September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2022; siliconchip.au/Series/384) reminded me of where I first saw the Kelvin connection. In the early 1960s, my employer bought a low-ohms meter from an English manufacturer, which used this connection in two shielded wire leads, with the outer braid for the supply current connections and the inner wires for the voltmeter connections.

The principle used was slightly different from that of your project in that a low, constant voltage source (unregulated) was used, via a switched range of calibrating resistances. The scale on the analog meter indicated infinity at full scale and zero at the left-hand end; the meter showed half-scale when the resistance under test was equal to the internal calibrating resistance.

This scaling was the reverse of that used in common analog meter resistance scales, which have zero at the right and infinity at the left.

At that time, the availability of mainly germanium transistors made it impractical to use a DC-coupled amplifier. So the designers opted for AC-coupling in the amplifier, with its input and output connected to an optical synchronous modulator/demodulator. The latter comprised light-dependent resistors illuminated by an incandescent lamp, with the light "chopped" by a motor-driven slotted disc.

As I recall, the amplifier itself consisted of three balanced stages of germanium transistors, with appropriate AC and DC feedback for stability, capacitively coupled at input and output. A manual control was used to calibrate the meter to full scale with the test leads open before taking a measurement.

For convenience, the meter scale was calibrated with "10" at centre scale, thus avoiding the need for decimal points at the low end of the scale. The unit gave satisfactorily accurate readings from "1" to "100" on each range, although I cannot remember what the ranges were, most likely ×1/100 to ×100.

Greg Mayman, Sturt, SA.

The satisfaction gained from repairing old hifi gear

I spent my whole working life in the electronics industry, starting my business at age 22 in 1967 and running it for 40 years. It was predominately repairing television receivers and antennae, but also audio and associated gear. The turntables were almost all Garrard or BSR with the occasional Dual, all with ceramic cartridges.

Now that I have 'retired', I have found a new activity that gives me immense satisfaction. A friend has a shop selling vinyl records, but to go with that, he also sells vintage amplifiers, speakers and high-quality turntables, with the very best magnetic cartridges, mainly from the seventies and eighties.

I service and repair these before they reach the shop. I regularly see top brands that my customers in the old days could never afford. I have gained much respect for the design effort put into this wonderful gear. Brands like Marantz, Technics, NAD, Quad, Sansui, Yamaha, Thorens etc, plus a few that are entirely new to me.

Most of these are non-operational when I receive them, and I must say that bringing them back to fully working condition is a really nice feeling.

It is pretty easy to download service manuals for free for nearly all the old gear. Repairing the mechanism for some of the turntables requires considerable mechanical

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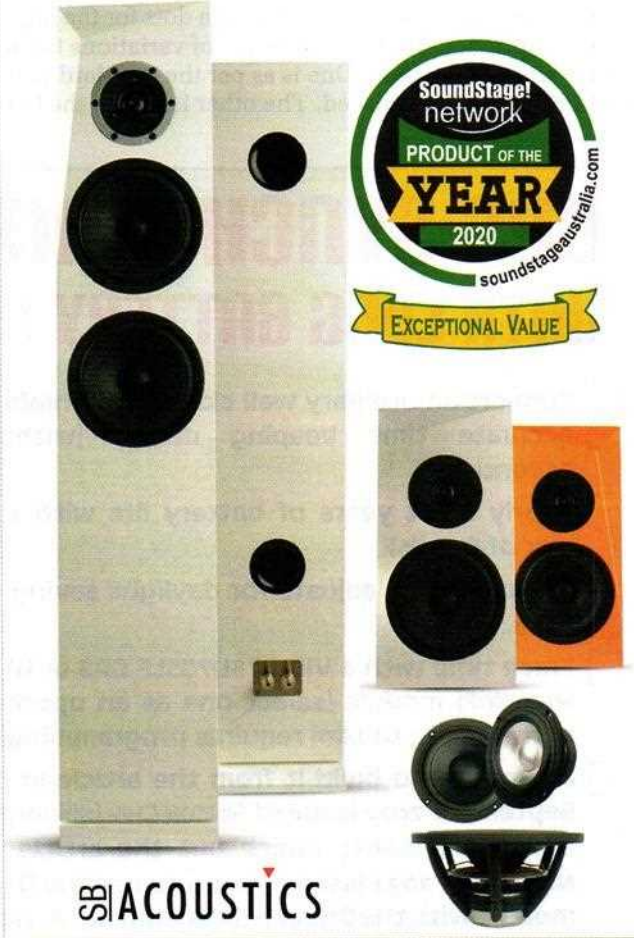

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skill, and of course, the amplifiers require good to excellent electronic skills as well. Sometimes we do cosmetics, respraying and cleaning. The shop owner is an expert in renovating the timber grain.

Manuals can be downloaded from websites like manualslib, hifiengine, vintageshifi etc. Rubber belts can be ordered by dimensions rather than by brand and model. While I do get paid for this, I have been surprised at the pleasure gained in turning great but old gear from landfill fodder to the pride of place in someone's lounge room.

A lot of the gear is nearly fifty years old and, when repaired, works so well, sounds so nice and should run for another twenty years.

Brian Healy, Mangerton, NSW.

Circuit junctions should not be ambiguous

I want to add a few comments about Brian Playne, who had difficulty reading four-wire junctions on a circuit diagram (Mailbag, August 2022, page 4).

AS/NZS 1102.103:1997 Part 103 "Graphical symbols for electrotechnical documentation, conductors and connecting devices" refers to this problem. It states that this form 2 (03-02-05), referred to by the reader, shall only be used if required by layout considerations.

The preferred form is Form 1 (03-02-04) double junction of conductors where the conductors are displaced and not cross over. As far as I know, the dots for the junctions are optional. There are a couple of variations to the double-junction method. One is as per the standard with two "T" junctions displaced. The other is where the two Ts are displaced and angled at the tip of the main joining conductor.

This is what I was taught at RMIT. The other reason for not using the crossover dot was because it could lead to an inadvertent blob of ink on the crossover point, which would look like a joint when none was intended. Newer inks may not have this problem, but that was the reason given when I learnt schematic drawing.

Hopefully, that helps your readers in understanding schematic drawings and how they should be for clarity, so mistakes are reduced when reading them.

Wolf-Dieter Kuenne, Bayswater, Vic.

Comment: the fact that we use a 'skip over' symbol when wires cross and do not join should mean that even if a blob of ink was to somehow land there (and we don't recall that happening any time in the last couple of decades), it should still be clear that there is no junction there.

Appreciation for designs using BASCOM

I enjoyed the Circuit Notebook articles and software by Mahmood Alimohammadi back in October & December 2016. I use BASCOM and find it an excellent language for non-professionals. Thanks for providing the software downloads as I learned a lot from viewing his code. I would appreciate any further BASCOM articles.

Graham Vayro, Logan Village, Qld.

Comment: you might want to look at the LC Meter Mk3 (November 2022), Silicon Labs FM/AM/SW Digital Radio (July 2021), AM/FM/SW Single-Chip Radio (January 2021), Shirt Pocket DDS Oscillator (September 2020) and plenty

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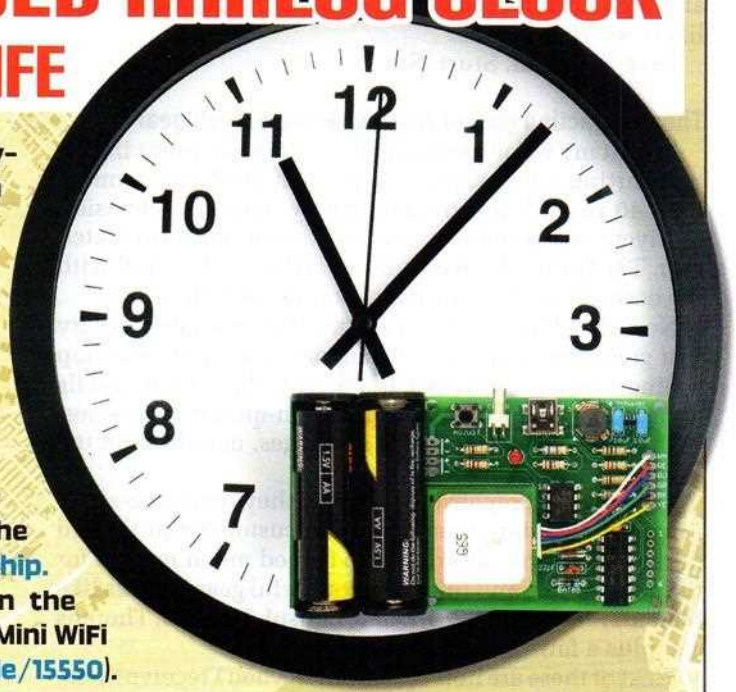
- Learn how to build it from the article in the September 2022 issue of Silicon Chip (siliconchip.au/Article/15466). Check out the article in the November 2022 issue for how to use the D1 Mini WiFi module with the Driver (siliconchip.au/Article/15550).



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more articles we published that utilise BASCOM code. See the full list (20 in total) at siliconchip.au/link/abhn

Distributed vs concentrated solar power

Thank you for the last few issues of SILICON CHIP magazine. They are always worth reading.

Earlier this year, I wrote that I believed that home-generated solar power could not be transmitted to the high voltage distribution networks via the distribution transformers. I still believe that I am correct.

However, if one looks at power distribution differently, the lack of load caused by the home generation is 'transmitted' to the high voltage networks by reduced demand on the large power generators. Of course, this means more power is available to other low-voltage networks. Effectively, power is being transmitted from one low-voltage network to another.

Also, power is effectively transferred between phases. Sometimes, one needs to stand on one's head to see the reality of a situation.

I am not a fan of home solar power generation and believe that large commercial solar farms are the correct way to access the sun's power. According to the following government website, there is a total of more than 11GW of panels on household roofs:

https://arena.gov.au/renewable-energy/solar/

However, the real-time power generation figures on the AEMO website show the home-generated power to be much less than that. Even allowing for clouds and dirty panels etc, home solar is significantly below its expected contribution to the grid. The figures justify my belief that home solar is a bad policy in general.

Full utilisation of home solar power is only possible when there is sufficiently high demand on the local low voltage network. Commercial solar farms are far better since they feed their power into the high voltage network, full utilisation can be achieved easily, and the investment is justified.

I am a supporter of pumped hydro energy storage for electricity grids and was pleasantly surprised when I discovered the amount of activity for pumped hydro schemes.

I was most surprised when I saw the number of pumped hydro projects in China. For a nation that can manufacture large quantities of batteries, the Chinese chose pumped hydro for grid power storage. See: https://w.wiki/5m6D

Unfortunately, I do not see much activity in Australia, probably because large pumped hydro schemes require huge amounts of money and take a long time to build. However, there are some schemes planned. One that I like very much is the small 1.5MW scheme in Western Australia. It should be finished and running very quickly: siliconchip.au/link/abh2

Finally, I found a document that lists possible Australian pumped hydro sites (siliconchip.au/link/abh3).

George Ramsay, Holland Park, Qld.

Advances in storage technology

Geoff Chapman wrote about the shrinking size of storage space. Consider the advances with micro SD cards. It is now possible to get a 1TB micro SD card (perhaps 2TB by the time I finish writing this). That little card can hold about 200 HD movies or maybe a couple of thousand in

...continued on page 12

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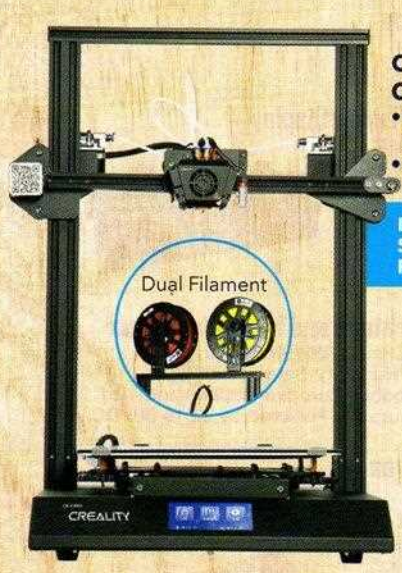

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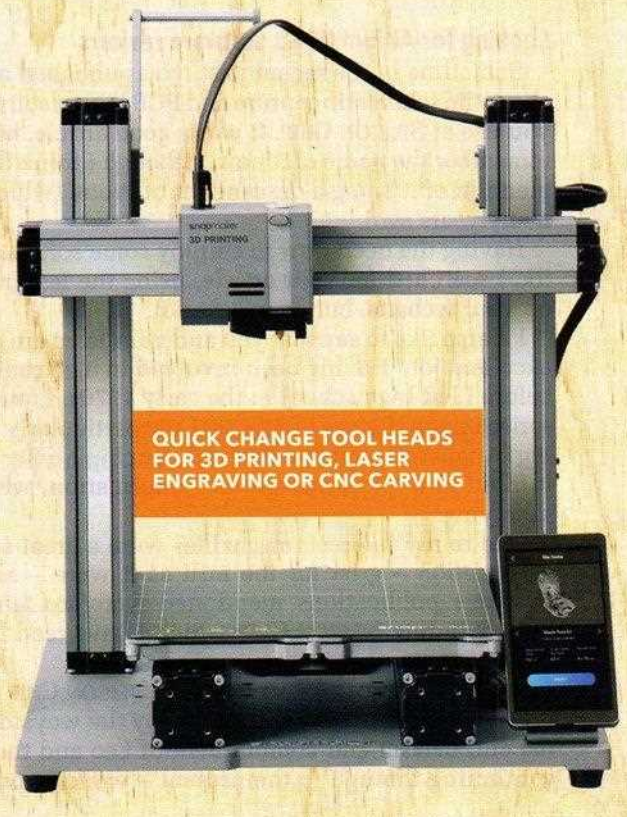

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	TL4432	TL4256	TL4411	TL4431	TL4610	TL4239	TL4620	TL4630
Build Size	220x220x250mm	150x150x150mm	300x300x400mm	250x220x200mm	200x170xInfinte	280x250x300mm	230x250x235mm	320x350x330mm
Frame Type	Open	Enclosed	Open	Enclosed	Open	Enclosed	Open	Open
Removable Bed	Yes	Yes	Yes	Yes	N/A	No	Yes	Yes
Flexible Bed	No	Yes	No	Yes	N	No	Yes	Yes
Layer Resolution	0.15 - 0.4µm	0.15 - 0.4µm	0.15 - 0.4	0.15 - 0.4µm	0.15 - 0.4µm	0.15 - 0.4µm	0.15 - 0.4µm	0.15 - 0.4µm
Max Print Speed	100mm/s	100mm/s	180mm/s	150mm/s	120mm/s	100mm/s	180mm/s	180mm/s
Extruder Drive	Bowden	Bowden	Bowden	Bowden	Bowden	Direct	Direct	Direct
Main Interface	Dial and button	Touch screen	Touch screen	Touch screen	Dial and button	Touch screen	Touch screen	Touch screen
Levelling System	Manual	Assisted	Auto	Assisted	Manual	Assisted	Auto	Auto
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VHS tape quality and fits in the space occupied by the record protect tab of a VHS tape. Simply amazing.

Horst Leykam, Dee Why, NSW.

Looking for Altium ECAD software reviews

Sometime in the recent past, you published an article about the schematic capture and PCB layout software that you use at SILICON CHIP. It was a good article, but I can't remember the name of it now, although I think there was mention of it being a descendant of Protel (which I used many years ago).

Having the need now to employ some software of that ilk, I searched for your article, using the features index on your website, but cannot find it.

I'd also like to say that you and your team are doing an excellent job! Having been involved in electronics since before I left high school in the early 1970s. I found Leo's series on the History of SILICON CHIP particularly interesting (August-September 2022; siliconchip.au/Series/385). It filled in a lot of background information, which was satisfying.

Due to my interest, magazines were a great source of information – grist for the mill as it were – so all the previous publications mentioned were/are familiar to me, including SILICON CHIP which I have read from the beginning.

It is, I suppose, no surprise that SILICON CHIP has survived when all others have fallen by the wayside, given the enthusiasm and commitment of Leo and the team – continuing through to the present – working on "your" magazine (which I like to think of in a somewhat proud Aussie way as "our" magazine as well).

The fact that you have taken on stewardship of the archives of all your predecessors is commendable in no small way. I could go on with hackneyed sayings like "keep up the good work" etc but suffice it to say that your efforts are greatly appreciated, and I thank you.

Russell Campbell, Leichhardt, NSW.

Response: We have published several articles that you could be referring to. It is likely one of the following:

- June 2022: Altium Designer 22 review by Tim Blythman (siliconchip.au/Article/15348)
- January 2021: Altium 365 and Altium Designer 21 review by Tim Blythman (siliconchip.au/Article/14705)
- December 2019: The new Altium Designer 20 review by Tim Blythman (siliconchip.au/Article/12176)
- April 2019: Altium Designer 19 review by Tim Blythman (siliconchip.au/Article/11527)
- January 2019: "CircuitMaker" free PCB software review by Tim Blythman (siliconchip.au/Article/11378)
- August 2018: Altium Designer 18 review by Nicholas Vinen (siliconchip.au/Article/11189)

The mail delivery blues

You are not alone in the mail saga. I recently sent a normal envelope via airmail to the city of Melbourne from the south island of New Zealand that took 49 days to be delivered! This is totally absurd and a courier was recommended instead, for $38 instead of $3.

The excuse is COVID-19 or a lack of staff; the latter

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SC6019 is a set of the critical parts needed to build one 500W Amplifier module (PCB sold separately; SC6367); see the parts list on the website for what's included. Most other parts can be purchased from Jaycar or Altronics.

Read the articles in the April – May 2022 issues of SILICON CHIP: siliconchip.com.au/Series/380

seems more likely. Attitudes have certainly changed in the last few years, and nobody seems to care anymore. Except those of us who read SILICON CHIP, for which libraries are often the most reliable option. They will eventually arrive...

Karen Wardell, Nelson, New Zealand.

An idea for a pill reminder project

Thanks for the magazine. I am glad you can keep it going – it is pretty well an Australian tradition now.

I have a simple project idea, possibly based on the Garbage & Recycling Reminder (January 2013; siliconchip.au/Article/1315).

This has come about as a function of getting older and the necessity to take tablets regularly – every morning/night/etc. Initially, I just remembered (and forgot) as it was all new to me. Then I set my phone alarm, but often I was not near the tablets when the alarm went off; I stopped the alarm and forgot to take them!

The tablets are put in a clear plastic flip-lid box weekly by the day and left on the kitchen bench. Invariably there is a distraction, and oops, forgotten again.

A flashing LED timer built into a similar tablet box ($2.00 from a dollar shop) with an LED for each day and a reset button would probably solve the problem, as did the garbage reminder that we have been using since inception; we now always get it right.

Peter Cave, Ormiston, Qld.

Comment: that is a great idea. However, commercially available reminders would likely be far cheaper than building one. We would find it difficult to produce such a device that matched the commercial ones for price and that they have convenient pill holders and easy programming. Our version would have to use a commercial pill holder that may not suit your needs. For example, see www.tabtimer.com.au/Electronic-Pill-Boxes

Software as a disservice

I just read the May 2022 Editorial by Nicholas and had to comment. As a long-time CorelDraw user, and on their annual subscription since 2017, I am in the same boat. Their value proposition was based on their cost/performance ratio compared to other solutions. My yearly cost for the CorelDraw Graphics Suite has been around $227, so $599 per year will not fly!

The FOSS (free/open-source software) alternatives are great but have limited adoption in our circles where native formats from Adobe or Corel are preferred.

At our hourly rate, the Creative Cloud All Apps subscription is less than two hours of work per user more expensive! We would get better integration and a much larger toolset by migrating to the Adobe offerings.

Having said that, their products are not known for being rock solid and stable either, which has been the main barrier to our migration to date when seen with their (previously) higher cost in context.

Chris Schlebusch, Brisbane, Qld.

Comments: InDesign is close to ideal for our work producing the magazine, so we're somewhat beholden to Adobe. As expensive as their Creative Suite subscription is, it is worth it for InDesign alone. It's harder to say that about the Corel suite as there are many more alternatives to their products. SC

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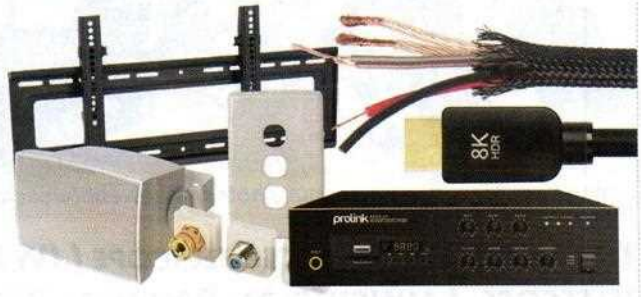

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ELECTRONIC PARTS / TOOLS / EQUIPMENT

JAMES WEBB SPACE TELESCOPE

BY DR DAVID MADDISON

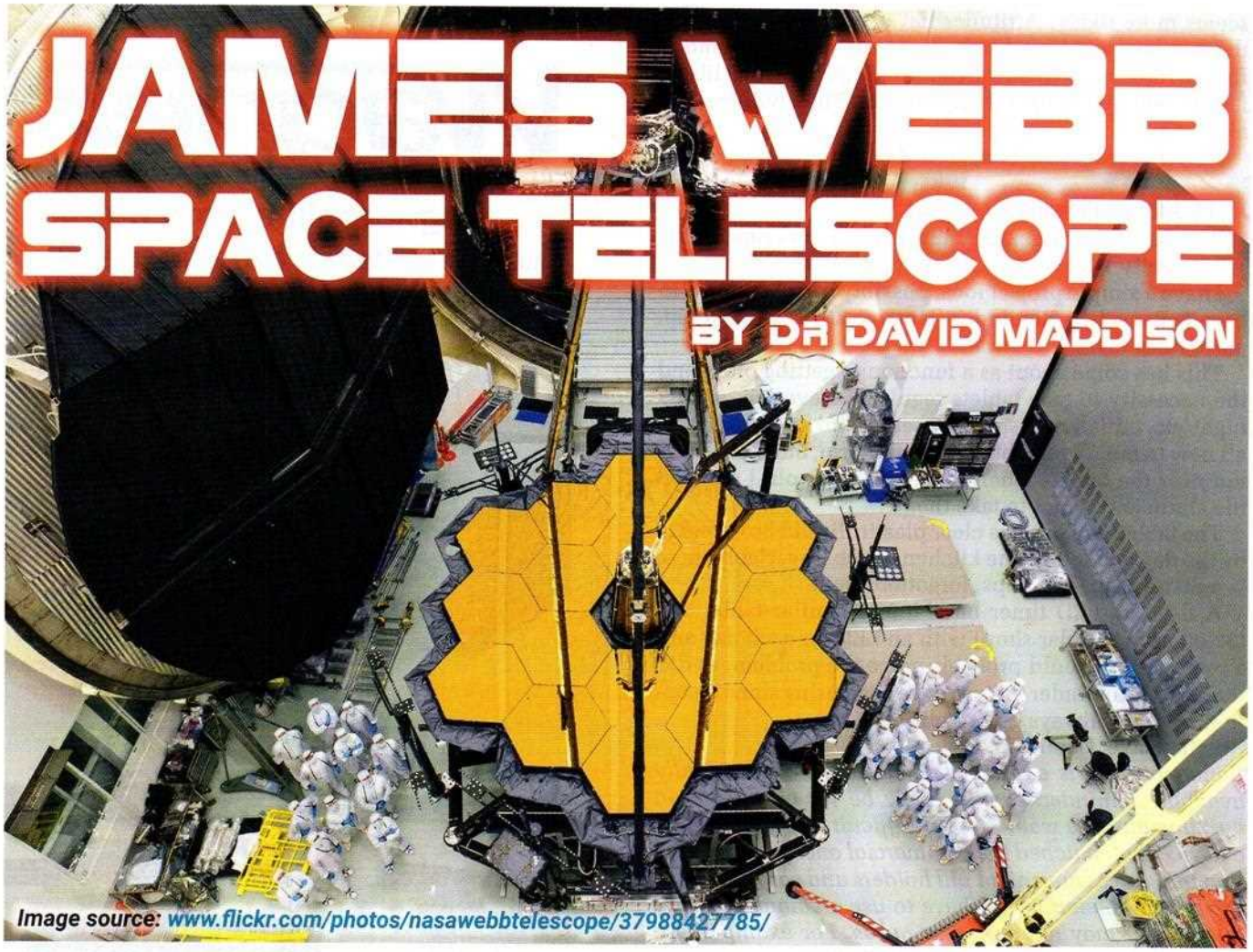


Image source: www.flickr.com/photos/nasawebbtelescope/37988427785/

THE JAMES WEBB SPACE TELESCOPE (JWST) IS THE NEWEST AND MOST ADVANCED SPACE TELESCOPE. LAUNCHED ON DECEMBER 25TH, 2021 ON AN ARIANE 5 ROCKET FROM FRENCH GUIANA, IT OFFICIALLY ENTERED SERVICE ON JULY 12TH, 2022. WHILE MUCH HAS BEEN SAID AND WRITTEN ABOUT IT IN THE PRESS, THIS ARTICLE WILL CONCENTRATE ON THE AMAZING TECHNOLOGY BEHIND IT.

The James Webb Space Telescope has the largest mirror of any telescope launched into space. It can see 'back in time' right up to the time of the first star and galaxy formation after the Big Bang (the presumed beginning of the universe).

It also has more light gathering ability than any other space telescope, allowing it to see very faint objects. It can see in the infrared, meaning it can image objects that are not visible using the visible light spectrum.

The JWST mission objectives are to explore the early universe, examine the evolution of galaxies over time, examine the star life cycle and look for and examine other planets. That includes our own minor planets, Kuiper Belt objects and the suspected Planet Nine in our solar system.

The JWST project is led by NASA in collaboration with the European Space Agency (ESA) and the Canadian Space Agency (CSA). Their academic and industry partners include the University of Arizona, Ball Aerospace, L3Harris Technologies, Lockheed Martin, Northrop Grumman and The Space Telescope Science Institute (see https://jwst.nasa.gov/content/meetTheTeam/team.html).

Design started in 1996, and in 1999, there was an expectation of a US$1 billion cost and a 2007 launch. The JWST has cost NASA US$9.7 billion ($14.1 billion) over the last 24 years, the ESA €700 million (A$1.02 billion) and the CSA C$200 million (A$224 million).

JWST vs Hubble

The JWST is a successor to the Hubble Space Telescope (HST), which entered service on May 20th, 1990 and

Who was James Webb?

The telescope was named after James E. Webb, NASA's second director, from 1961 to 1968. He oversaw the Mercury, Gemini and Apollo missions with a total of 75 launches.

Image source: NASA

is still in operation today. However, the JWST does not replace the HST. Hubble has an uncertain remaining lifetime partly because NASA's Space Shuttle fleet was retired in 2011, so there is no longer any way to service it. Despite that, it will be kept in service as long as possible.

A fundamental difference between the JWST and the HST is the size of the primary mirror. The HST has a 2.4m diameter mirror while JWST's is 6.5m in diameter (see Fig.1). They are also designed to image different light wavelength ranges (Fig.2).

The HST has an effective light gathering area of $4m^2$ and the JWST $25m^2$, so the JWST has 6.25 times the light gathering capability of the HST.

The HST was designed for the visible and ultraviolet part of the light spectrum, plus some infrared, while the JWST is designed to work mainly in the infrared. All objects with a temperature above absolute zero (-273°C) emit infrared radiation, making them visible to JWST as long as they give off enough infrared light.

Specifically, HST images wavelengths of 100nm to 800nm with some parts of the infrared spectrum from 0.8µm (800nm) to 2.5µm, while the JWST images from 0.6µm to 28µm.

The infrared spectrum extends from 0.75µm to a few hundred microns, so the JWST works mainly in that area with a small capability in the visible range from 600-750nm (orange is 590 to 620nm and red is 620 to 750nm).

As infrared radiation comes from all objects, it is essential to keep the JWST as cool as possible. Hence its vast multi-layer sunshield, its remote orbit away from the Earth and the Moon and onboard cooling systems. It must be kept below -223°C to keep it from interfering with itself from self-emission of infrared. The electronics onboard operate at higher temperatures than that, though.

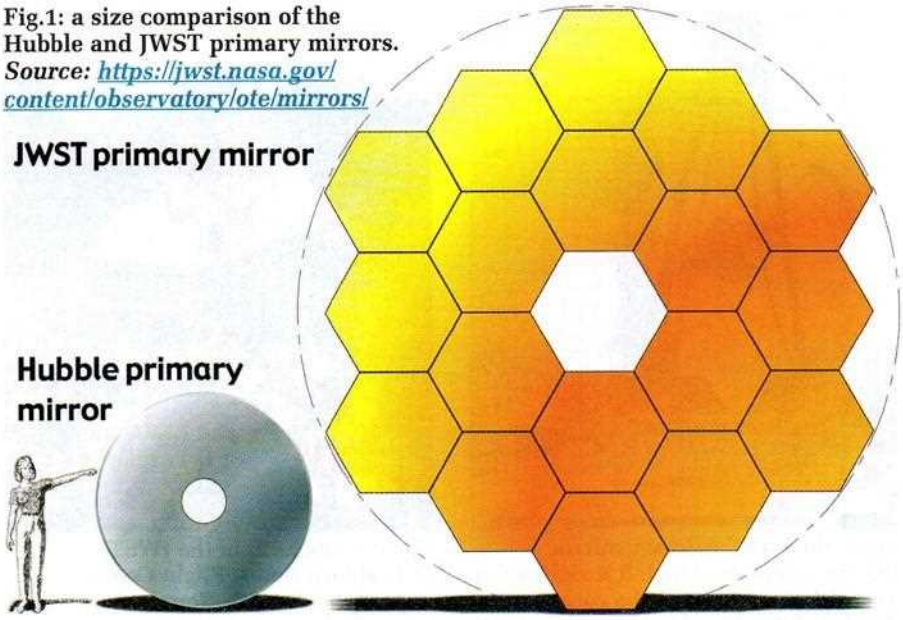
JWST can detect objects 100 times fainter than the HST. JWST can also see objects as old as 180 million years after the Big Bang, compared to 400 million years for HST.

Physical structure

The JWST consists of four major sections (see Fig.3):

1. The spacecraft bus, which is like a chassis but also houses the following subsystems:
   - Electrical Power Subsystem

Fig.1: a size comparison of the Hubble and JWST primary mirrors. *Source:* https://jwst.nasa.gov/content/observatory/ote/mirrors/



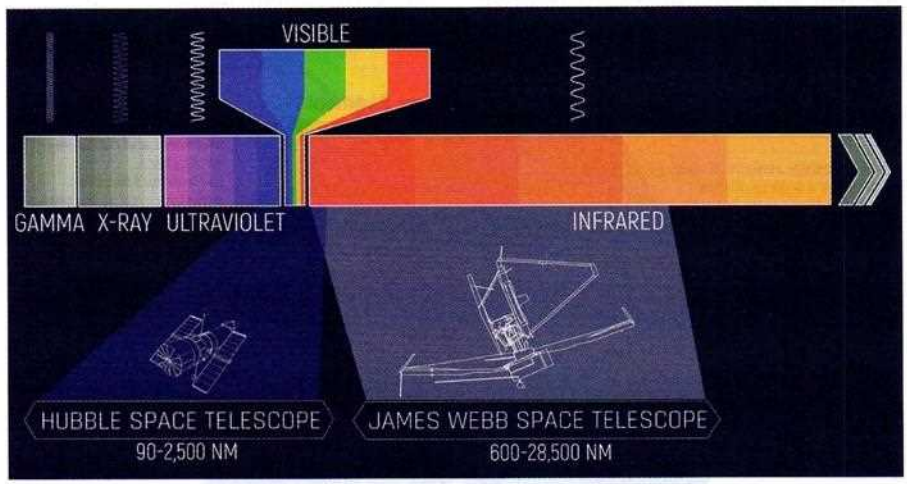


Fig.2: a comparison of the light spectrum coverage of the HST & JWST. *Source:* www.nasa.gov/content/goddard/hubble-vs-webb-on-the-shoulders-of-a-giant

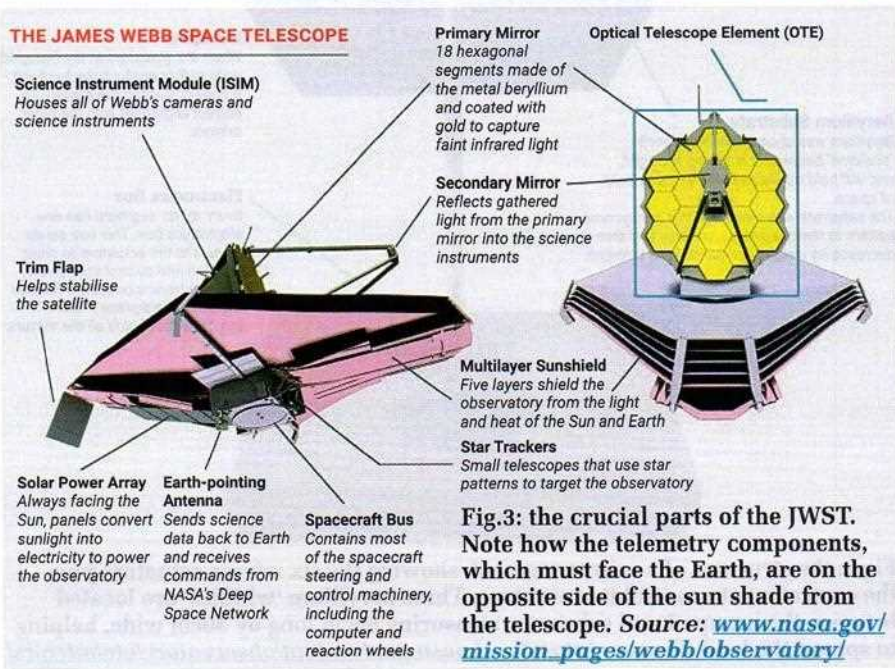

THE JAMES WEBB SPACE TELESCOPE
Science Instrument Module (ISIM)
Houses all of Webb's cameras and science instruments
Primary Mirror
18 hexagonal segments made of the metal beryllium and coated with gold to capture faint infrared light
Optical Telescope Element (OTE)
Secondary Mirror
Reflects gathered light from the primary mirror into the science instruments
Trim Flap
Helps stabilise the satellite
Multilayer Sunshield
Five layers shield the observatory from the light and heat of the Sun and Earth
Star Trackers
Small telescopes that use star patterns to target the observatory
Solar Power Array
Always facing the Sun, panels convert sunlight into electricity to power the observatory
Earth-pointing Antenna
Sends science data back to Earth and receives commands from NASA's Deep Space Network
Spacecraft Bus
Contains most of the spacecraft steering and control machinery, including the computer and reaction wheels

Fig.3: the crucial parts of the JWST. Note how the telemetry components, which must face the Earth, are on the opposite side of the sun shade from the telescope. *Source:* www.nasa.gov/mission_pages/webb/observatory/

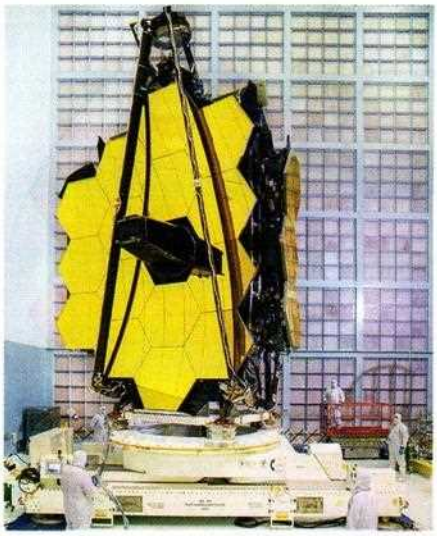


Fig.4: the JWST primary mirror during assembly. The left & right sides are folded to fit inside the rocket. *Source:* https://jwst.nasa.gov/content/observatory/ote/mirrors/

Fig.5: a mock-up of the JWST at Goddard Space Flight Center in Maryland, USA. *Source:* www.flickr.com/photos/nasawebbtelescope/8518326611

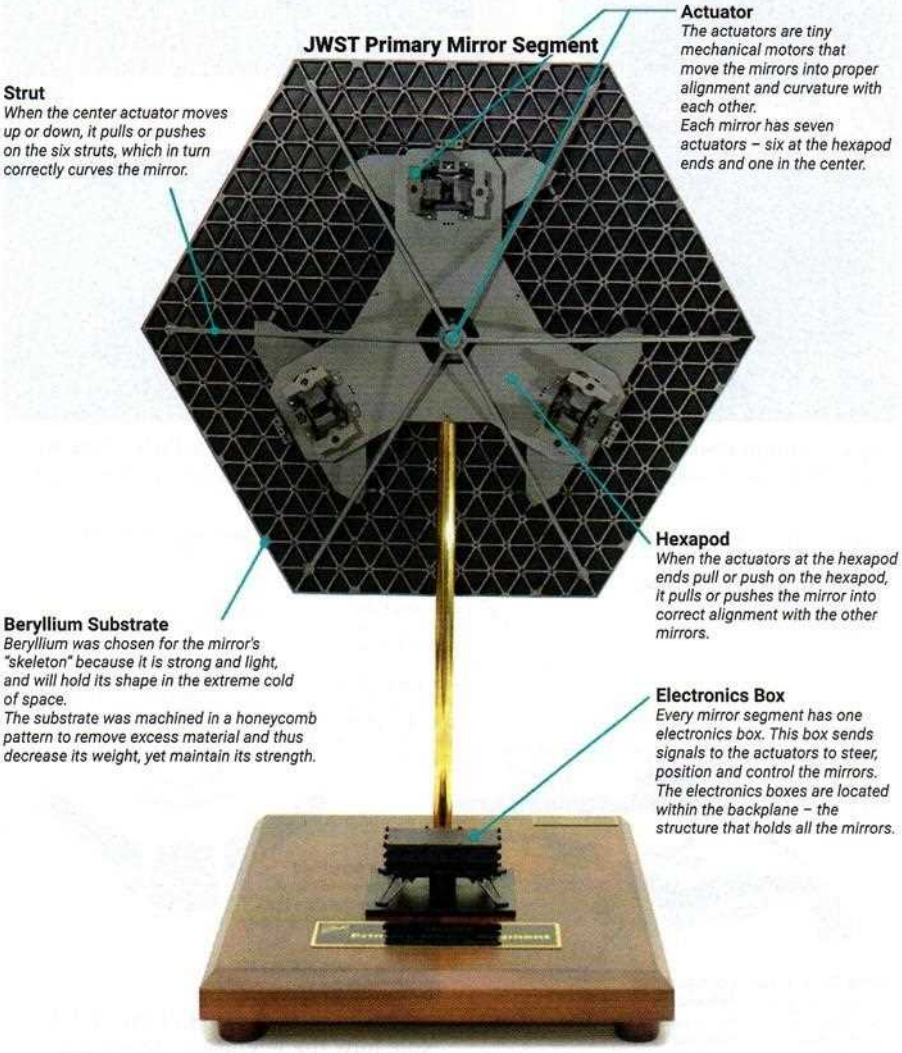

JWST Primary Mirror Segment
Actuator
The actuators are tiny mechanical motors that move the mirrors into proper alignment and curvature with each other.
Each mirror has seven actuators – six at the hexapod ends and one in the center.
Strut
When the center actuator moves up or down, it pulls or pushes on the six struts, which in turn correctly curves the mirror.
Hexapod
When the actuators at the hexapod ends pull or push on the hexapod, it pulls or pushes the mirror into correct alignment with the other mirrors.
Beryllium Substrate
Beryllium was chosen for the mirror's "skeleton" because it is strong and light, and will hold its shape in the extreme cold of space.
The substrate was machined in a honeycomb pattern to remove excess material and thus decrease its weight, yet maintain its strength.
Electronics Box
Every mirror segment has one electronics box. This box sends signals to the actuators to steer, position and control the mirrors.
The electronics boxes are located within the backplane – the structure that holds all the mirrors.

Fig.6: the structure of a mirror segment, showing the six mirror actuators plus the central one to control its curvature. Three beryllium 'whiffles' are located between the hexapod and substrate, measuring 60cm long by 30cm wide, helping to spread the load. *Source:* https://jwst.nasa.gov/content/observatory/ote/mirrors/

- Attitude Control Subsystem
- Communication Subsystem
- Command and Data Handling Subsystem
- Propulsion Subsystem
- Thermal Control Subsystem

2. The optical telescope element (OTE), comprising the various mirrors.

3. The Integrated Science Instrument Module (ISIM), containing the cameras and other instruments such as NIRCam, NIRSpec, NIRISS and MIRI.

4. The Sunshield.

Size and weight

According to the ESA, the launch mass of the observatory was 6200kg, including the observatory, on-orbit consumables and launch vehicle adaptor. Its overall height is about 8m. The 705kg mirror is 6.5m in diameter and the focal length of the telescope optics is 131.4m.

The mirror

The JWST mirror and the rest of the spacecraft were far larger than could be accommodated by the Ariane 5 launch vehicle, so it had to be folded for launch, as partially shown in Fig.4. This was particularly challenging for the mirror, given the high level of precision required.

The mirror comprises 18 hexagonal gold-coated beryllium metal segments (Fig.6), each weighing about 20.1kg and 1.32m across, with a total diameter of 6.6m and a total area of $25m^2$.

Each mirror segment forms a primary mirror segment assembly (PMSA), weighing 39.48kg with actuators and other accessories. 48g of gold is used to coat the mirror, about the volume of a marble and the mass of a golf ball. Gold is used because it is highly reflective in the infrared.

The primary mirror segments each have six actuators to adjust their alignment, as does the secondary mirror. Primary mirrors also have a central actuator to adjust the mirror curvature.

Each segment had to be aligned with an accuracy of 7nm or one ten-thousandth the thickness of a human hair.

The actuators can move to positions as accurate as 1nm or one-millionth of a millimetre. In use, the mirrors are realigned every 10 to 14 days. There are a total of 132 actuators, including 126 for the primary mirror. The mirrors are ground to a mean surface

accuracy of better than 25 nanometres.

Diffraction spikes

Most images of stars make them look like a point of light or a disc with four or more radial spikes in a specific pattern. These spikes are called diffraction spikes – see Fig.7. They are a common phenomenon in reflector telescopes (like the JWST) and are partly related to the support vanes of the secondary mirror.

They are also common in any camera or telescope aperture that is non-circular, including the iris diaphragm of a traditional camera. In the case of the JWST, they also derive from the fact that the primary mirror is not circular.

They occur because light interacts and diffracts around the edges of the aforementioned structures. So the JWST has two sources of diffraction spikes. These are designed so that they do not overlap with each other and remain as narrow as possible. Fig.8 is a comparison of the diffraction spikes between the HST and JWST.

Sunshield

Apart from the mirror, the sunshield is the most prominent feature with a deployed size of 21.2m x 14.2m or about the size of a tennis court – see Figs.5 & 9. It shields the telescope from heat and light from the Sun, Earth and Moon. It is made of thin aluminium and doped-silicon coated plastic called Kapton E, with five separate layers each 0.025mm thick.

'Rip stop' structures are built into the shield material to prevent a tear catastrophically propagating through an entire layer.

You can check the sunshield and instrument temperatures at the website: siliconchip.au/link/abgu

At the time of writing, the layer on the sun side has a temperature of 13°C and 50°C (measured at two locations), while the innermost layer has temperatures between -231°C and -236°C. The five instruments were at temperatures from -235°C to -267°C.

Scientific instruments

The Integrated Science Instrument Module (ISIM) is behind the main mirror and holds the four scientific instruments plus the Fine Guidance Sensor, a camera for aligning the observatory. It also has power supplies, computers and instrument cooling – see Fig.10.

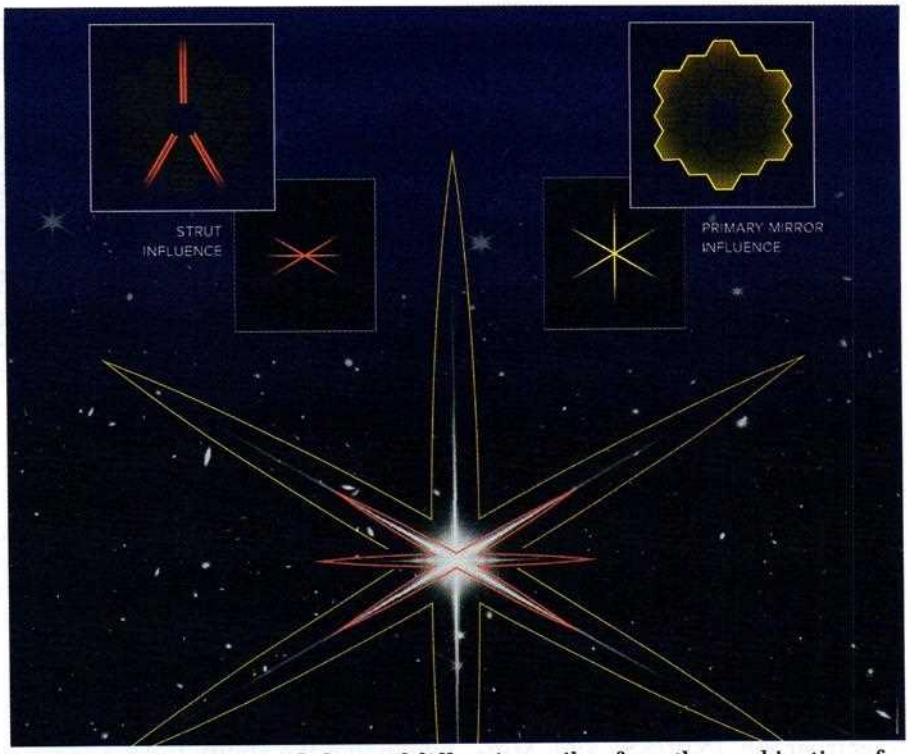


Fig.7: the contribution and shape of diffraction spikes from the combination of the JWST struts and mirror shape. *Source:* https://webbtelescope.org/contents/media/images/01G529MX46J7AFK61GAMSHKSSN

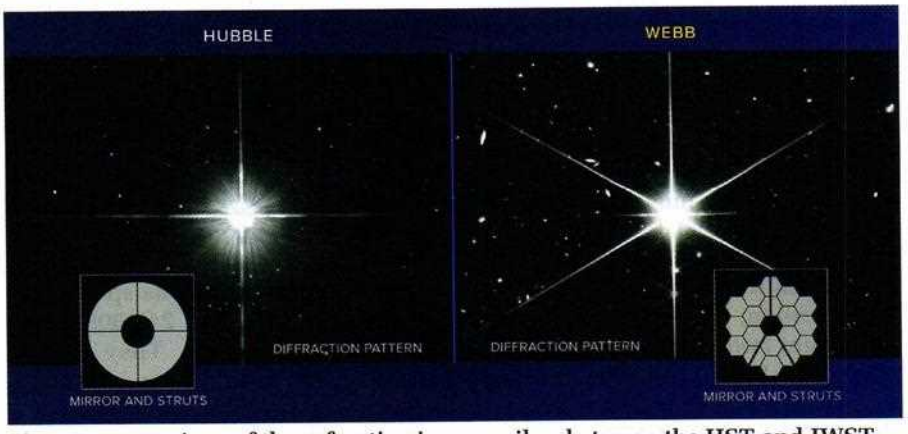
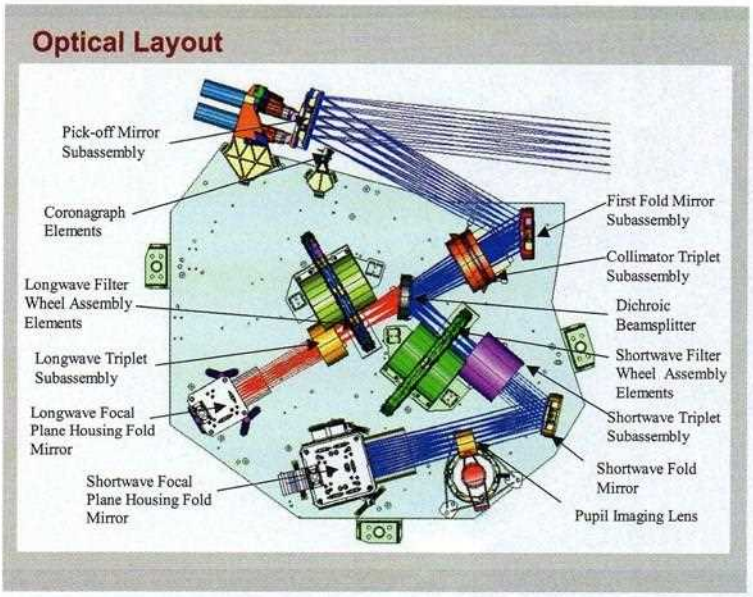


Fig.8: a comparison of the refractive image spikes between the HST and JWST.

Fig.9: the JWST's sunshield comprises five layers of Kapton film. *Source:* https://jwst.nasa.gov/content/observatory/sunshield.html

Fig.10: the ISIM compartment. *Source:* www.flickr.com/photos/nasawebbtelescope/30785200072/



◀ **Fig.11: the NIRCam configuration.** ***Source:*** *www.astro.princeton.edu/~jgreene/ast303/NIRCam-pocket-guide.pdf*

Fig.12: the NIRCam instrument (near-infrared camera). ***Source:*** *www.flickr.com/photos/nasawebbtelescope/albums/72157627248683106*

The four scientific instruments are the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), Near-infrared Imager and Slitless Spectrograph (NIRISS) and Mid-Infrared Instrument (MIRI)

As their names imply, these all work in the infrared. See Fig.13 for their specific wavelength ranges. We will go over each instrument in detail:

NIRCam (0.6-5µm wavelength range, Figs.11 & 12) is an infrared camera that has 10 mercury-cadmium-telluride (HgCdTe) detector arrays, each with four megapixels (4MP; 2048 × 2048 pixels). It is also used for "wavefront sensing" to align the mirror segments.

In addition, it has coronographs to block light from stars with associated exoplanets (planets outside our solar system). It operates at -236°C while its electronics operate at 17°C.

NIRSpec (0.6-5.3µm, Figs.16 & 18) is a spectrometer that can be used to analyse the chemical composition of objects. It has several operating modes, including the ability to take spectra of 100 objects simultaneously. The instrument runs at -235°C.

Fig.14: there are four arrays, each containing 62,000 shutters (measuring 0.1 × 0.2mm). ***Source:*** *https://jwst.nasa.gov/content/about/innovations/microshutters.html*

Multiple simultaneous spectra are taken with the aid of 248,000 micro shutters (see Fig.14). They can be individually opened or closed to allow light from the objects of interest through to the spectrometer via gratings and a prism to split up the light into its component wavelengths – see https://w.wiki/5hex

NIRISS (0.6-5um, Fig.17) is used for imaging and spectroscopy. It is combined with the Fine Guidance Sensor (FGS) used to guide the telescope. The FGS (Fig.19) finds pre-selected guide stars from a database and uses those for guidance.

Together, the instrument is known as the FGS-NIRISS (Fig.15); they are optically separate but contained within one assembly.

NIRISS was built by the Canadian Space Agency.

The detector for NIRISS is a 2048 × 2048 pixel (4MP) HgCdTe array with 18 × 18µm pixels. NIRISS is used for near-infrared imaging, wide-field slitless spectroscopy, single object slitless spectroscopy and aperture masking interferometry.

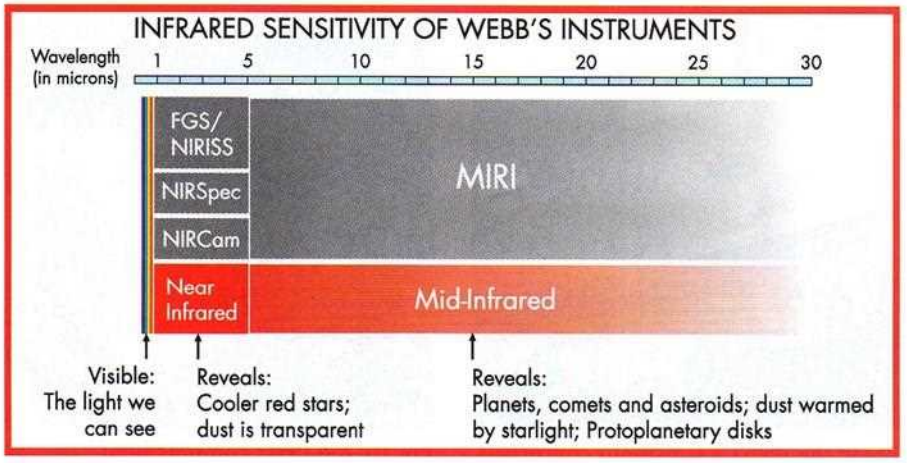


Fig.13: the JWST instrument light detection wavelength ranges, mainly in the infrared part of the spectrum. ***Source:*** *www.nasa.gov/mission_pages/webb/news/geithner-qa.html*

Fig.15: a photograph of the completed FGS-NIRISS assembly. *Source: John Brebner, Communications Research Centre*

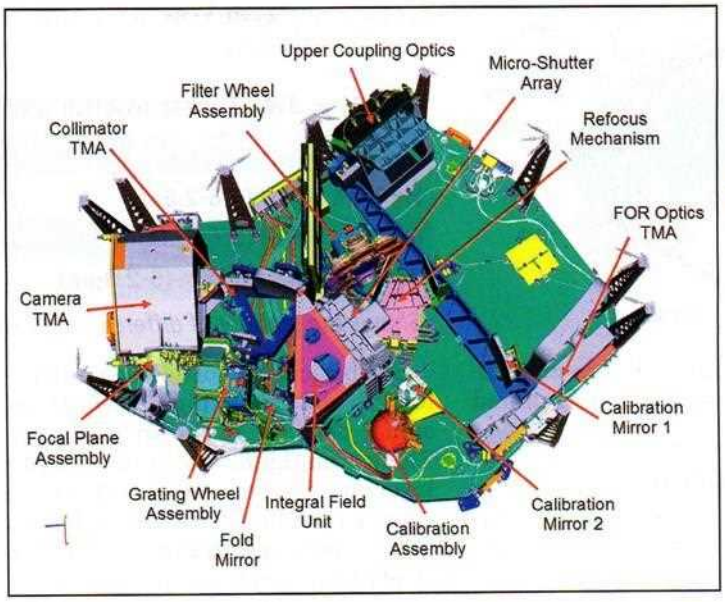


Fig.16: a schematic view of the NIRSpec instrument. *Source: https://w.wiki/5gyc*

Spectroscopy enables the chemical composition and physical structure of distant objects to be determined from their emission spectra. Slitless spectroscopy is used in sparsely-populated star fields to determine the spectrum of many objects at once. Aperture masking interferometry is used to resolve closely spaced objects such as a binary star system.

MIRI (4.9-28.8µm, Fig.20 overleaf) is a camera and imaging spectrometer. It can see longer wavelength infrared light than the other instruments and thus needs to be kept much colder. It operates at -267°C and has its own 'cryocooler' cooling system, shown in Fig.21 (also overleaf).

The cooling system is spread over several regions of the ISIM, all of which are at different temperatures. Like NIRCam (0.6-5µm), it has four coronagraphs to block starlight when

◀ Fig.18: a photograph of the NIRSpec instrument. *Source: https://w.wiki/5gyd*

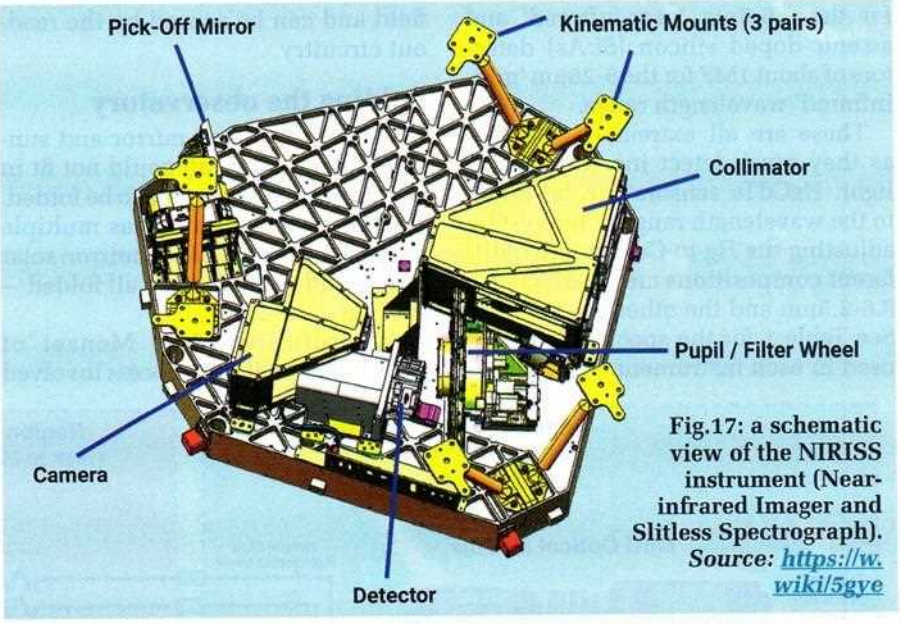


Fig.17: a schematic view of the NIRISS instrument (Near-infrared Imager and Slitless Spectrograph). *Source: https://w.wiki/5gye*

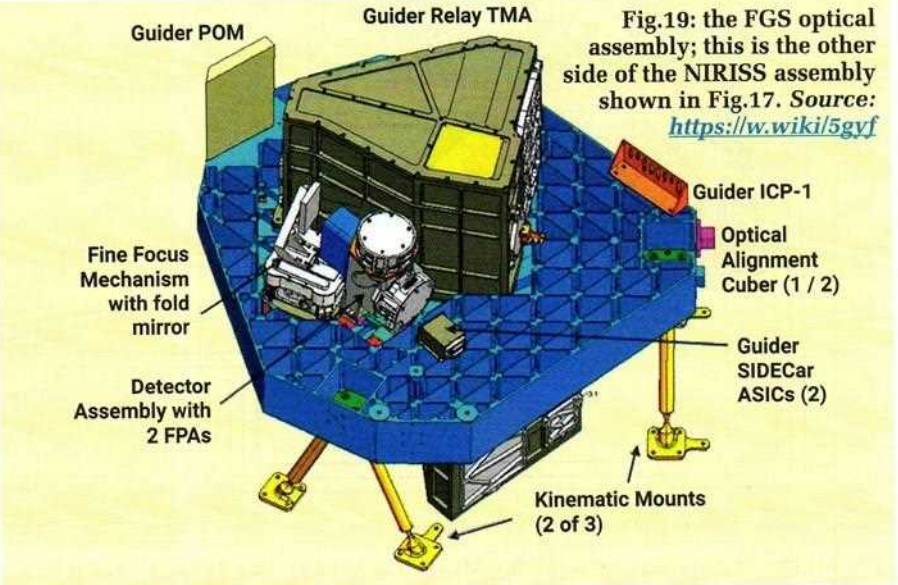

Guider POM
Guider Relay TMA
Guider ICP-1
Optical Alignment Cuber (1 / 2)
Fine Focus Mechanism with fold mirror
Guider SIDECar ASICs (2)
Detector Assembly with 2 FPAs
Kinematic Mounts (2 of 3)

Fig.19: the FGS optical assembly; this is the other side of the NIRISS assembly shown in Fig.17. *Source: https://w.wiki/5gyf*

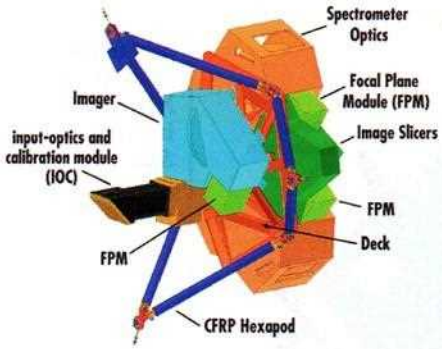


Fig.20: a schematic view of the MIRI (Mid Infrared Instrument). *Source:* https://w.wiki/5gyg

observing exoplanets. It uses arsenic-doped silicon arrays as its infrared sensors.

Infrared detectors

The infrared detectors are essential for the operation of the scientific instruments described above. There are two types, 4MP HgCdTe arrays for the 0.6-5µm 'near-infrared' and arsenic-doped silicon (Si:As) detectors of about 1MP for the 5-28µm 'mid-infrared' wavelength range.

These are all extremely sensitive as they must detect incredibly faint light. HgCdTe sensors can be tuned to the wavelength range of interest by adjusting the Hg-to-Cd ratio; two different compositions are used, one for 0.6-2.5µm and the other for 0.6-5µm. See Table 1 for the specific detectors used in each instrument.

Table 1 – JWST instruments and their detectors

	NIRCam	NIRSpec	FGS/NIRISS	MIRI
HgCdTe H2RG (0.6-2.5µm)	8			
HgCdTe H2RG (0.6-5µm)	2	2	3	
Arsenic doped silicon (5-2.8µm)				3

Shows the number of different types of IR detectors used in each instrument.

The basic layout of one of the detectors is shown in Fig.22, while an actual detector is shown in Fig.23. There is an HgCdTe or Si:As absorber layer on a silicon readout chip. When a light photon strikes the absorber, one or more electron-hole pairs are created. The electrons and holes move under the influence of an electric field and can be sensed by the readout circuitry.

Folding the observatory

With such a large mirror and sunshield, the spacecraft could not fit in any rocket and so needed to be folded. That is why the mirror has multiple segments. The sunshield, mirror, solar panels and antenna were all folded – see Figs.24 & 25.

According to Mike Menzel of NASA, the unfolding process involved hundreds of possible "single points of failure". JWST has 344 known possible single-points-of-failure, about 80% related to the unfolding process.

There were 144 release mechanisms for the unfolding process, all of which had to work perfectly. Naturally, all such mechanisms got special attention during design, assembly and testing to ensure they would work. There were also contingency plans for any deployment failure that might have occurred, some as simple as re-sending a command.

The most important thing that had to work first was the solar array deployment.

For a video of the unfolding (deployment) sequence, see the video titled "James Webb Space Telescope Deployment Sequence (Nominal)" at https://youtu.be/RzGLKQ7_KZQ

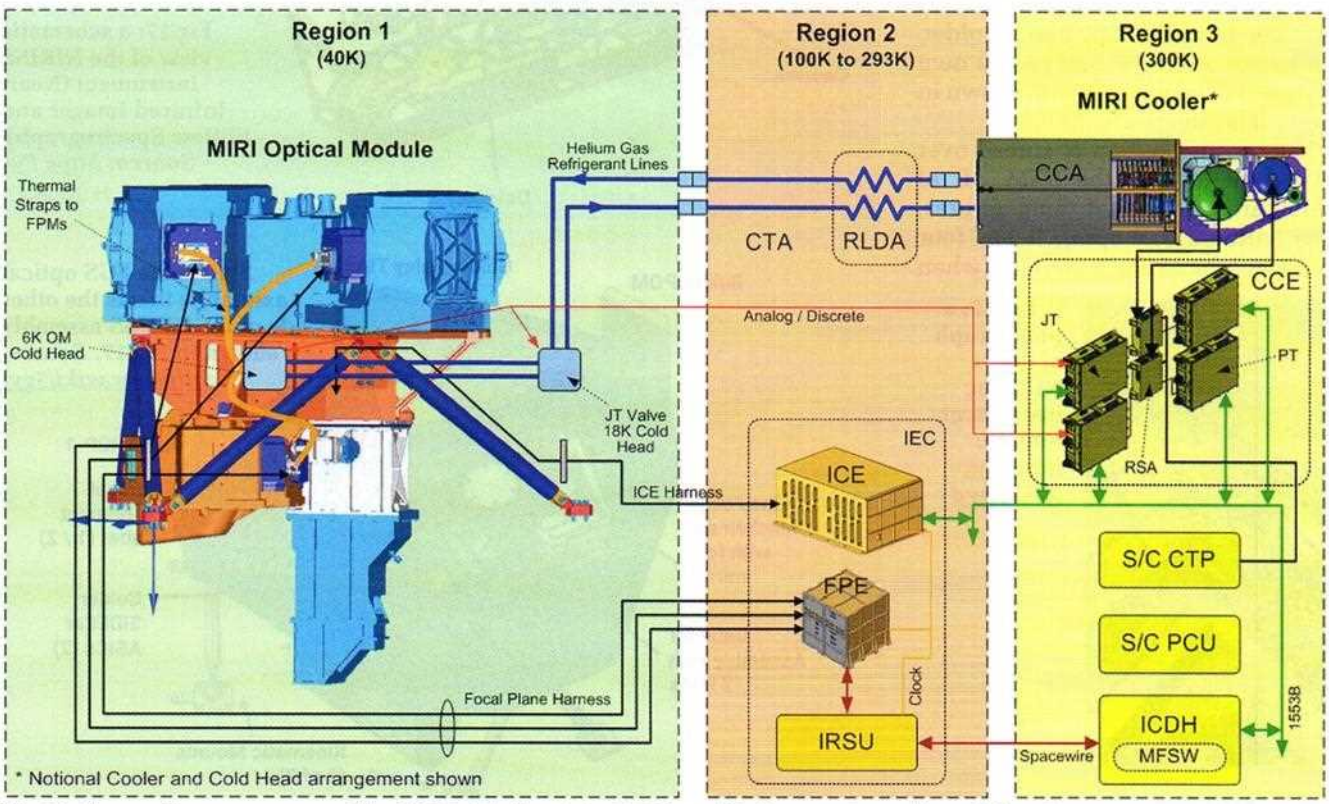


Fig.21: the cooling arrangement for MIRI; it is kept at -267°C or 6K. *Source:* https://w.wiki/5gyi

The JWST's orbit

JWST orbits a Lagrange point. These are five special points in space in the Earth-Moon system. At the L4 and L5 Lagrange points, there is an equal gravitational pull from the Earth, Moon and Sun, meaning that (in theory) an object can remain there indefinitely (asteroids are known to accumulate there).

The L1, L2 and L3 points are only metastable; for an object to stay there, it must expend minimal fuel for station-keeping. Objects can reside there for a long time, but not indefinitely.

Unlike most satellites but like some other space telescopes, the JWST orbits in a 'halo orbit' around the L2 Lagrange Point (see Fig.26). It is way beyond the orbit of the Moon, 1,500,000km from the Earth. In contrast, Hubble orbits the Earth at an altitude of only 550km.

The reason for orbiting L2 is to avoid the heat radiated from the Sun, Earth and Moon, which would swamp its sensitive infrared instruments. JWST can maintain the same orientation, so its sunshield will continue to protect the telescope. JWST's view will never be blocked by the shadow of the Earth or the Moon, unlike Hubble, which is in Earth's shadow every 90 minutes.

JWST takes six months to complete its halo orbit. In this orbit, JWST is in continuous contact with NASA's Deep Space Network with stations in Australia, Spain and California.

For more on the orbit, see the video titled "Animation: The James Webb Space Telescope's Orbit" at https://youtu.be/6cUe4oMk69E

Comparing images from JWST and HST

The 'Deep Field' images shown in Figs.27 & 28 (overleaf) are the same area of space taken using the JWST and HST. In astronomy, Deep Field means a very long exposure.

The JWST Deep Field image was its first, taken with its Near-Infrared Camera (NIRCam) using several wavelengths and a 12.5 hour exposure time. It shows the galaxy cluster SMACS 0723 which, due to its great mass, acts as a 'gravitational lens', distorting light from galaxies behind it into a circular pattern.

The HST image needed to be exposed for weeks. Despite that, it shows much less detail due to its smaller mirror and inability to image objects in the infrared.

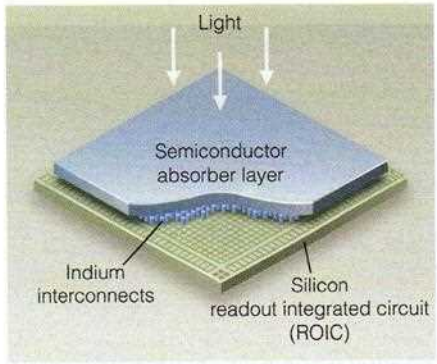


Fig.22: a schematic view of an infrared detector sensor used in several JWST instruments. *Source:* https://jwst.nasa.gov/content/about/innovations/infrared.html

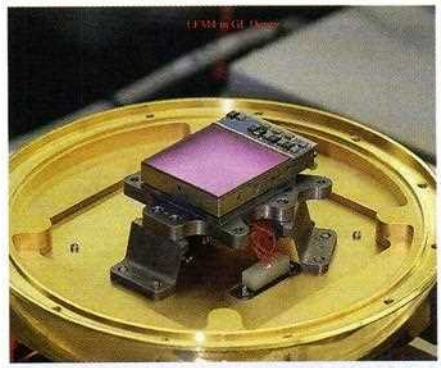


Fig.23: an infrared detector as used in the NIRCam instrument. Light is collected on the mauve HgCdTe film. *Source:* https://jwst.nasa.gov/content/about/innovations/infrared.html

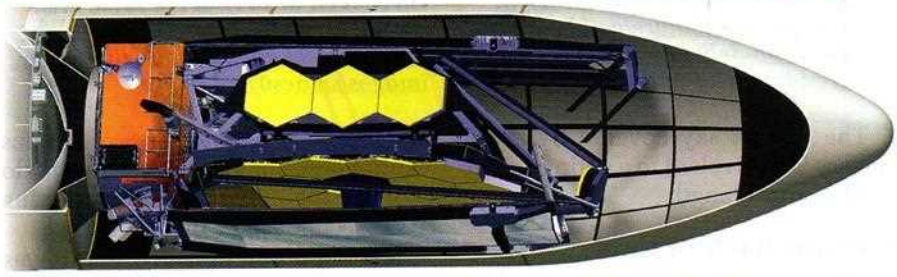
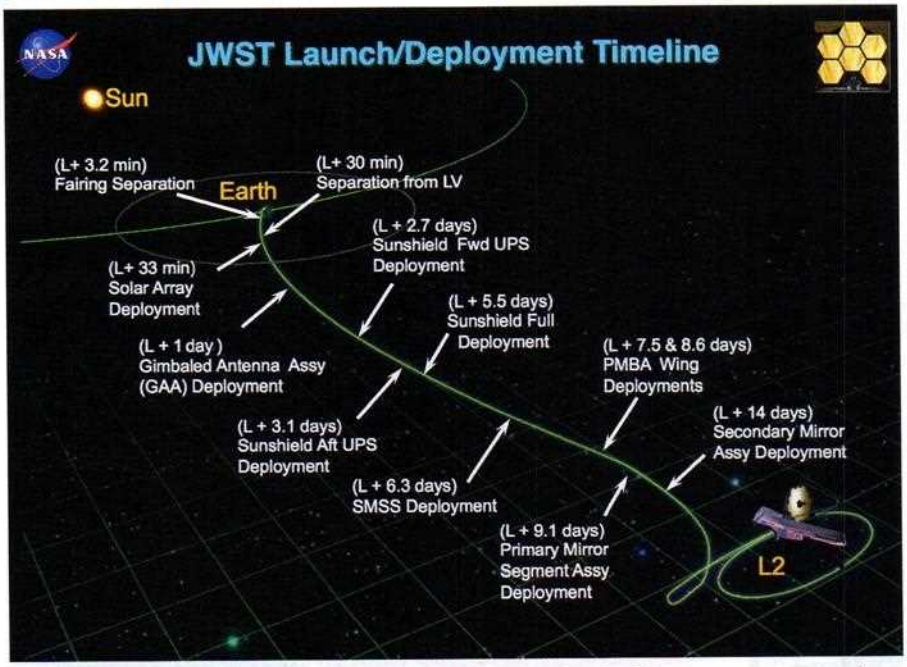
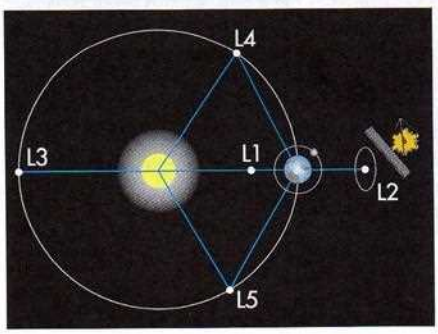


Fig.24: this shows how the JWST was folded inside the fairing of the Ariane 5 launch vehicle. *Source:* https://jwst.nasa.gov/content/about/launch.html#postLaunchDeployment


JWST Launch/Deployment Timeline
Sun
Earth
(L+ 3.2 min) Fairing Separation
(L+ 30 min) Separation from LV
(L+ 33 min) Solar Array Deployment
(L + 2.7 days) Sunshield Fwd UPS Deployment
(L + 5.5 days) Sunshield Full Deployment
(L + 1 day) Gimbaled Antenna Assy (GAA) Deployment
(L + 7.5 & 8.6 days) PMBA Wing Deployments
(L + 3.1 days) Sunshield Aft UPS Deployment
(L + 14 days) Secondary Mirror Assy Deployment
(L + 6.3 days) SMSS Deployment
(L + 9.1 days) Primary Mirror Segment Assy Deployment
L2

▲ Fig.25: the deployment sequence of JWST. LV is launch vehicle, UPS is Unitized Pallet Structure, PMBA is Primary Mirror Backplane Assembly and SMSS is Secondary Mirror Support Structure. *Source:* https://w.wiki/5gyj



◀ Fig.26: this shows the Lagrange points around the Earth-Sun-Moon system and the location of the JWST in a halo orbit around L2. *Source:* https://jwst.nasa.gov/content/about/orbit.html

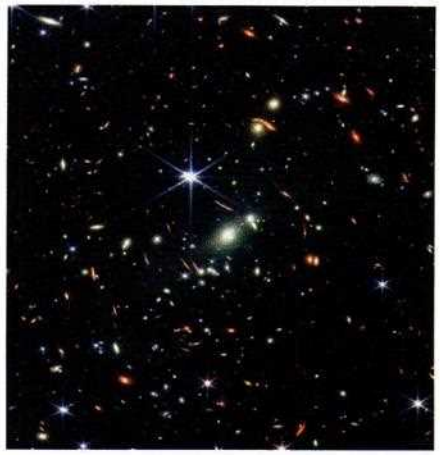


Fig.27: the first and iconic Deep Field image from the JWST. *Source:* www.nasa.gov/image-feature/goddard/2022/nasa-s-webb-delivers-deepest-infrared-image-of-universe-yet

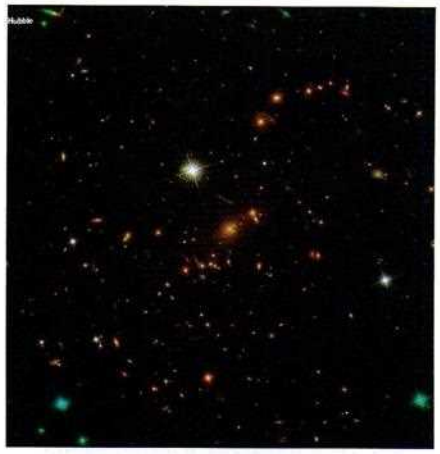


Fig.28: a Deep Field image from the HST taken in 2017 of the same area shown in Fig.27. *Source:* https://archive.stsci.edu/prepds/relics/color_images/smacs0723-73.html

The area of sky covered by these images is equivalent to a grain of sand held at arm's length.

Looking back in time

One objective of the JWST mission is to 'look back in time' at the early universe. What does that mean? To understand, we first have to consider the beginning of the universe.

According to accepted theories of cosmology, the universe started in a 'Big Bang'; it came into being suddenly from a 'singularity' of infinite temperature and density and infinite smallness. The known laws of physics cannot describe the singularity but do more-or-less apply for periods starting 10^{-43} seconds after the Big Bang.

It is important to realise that it was not an explosion in the conventional sense, but a sudden expansion of the very fabric of space-time itself for reasons not fully understood. It might have been due to some sort of quantum fluctuation.

Light and objects cannot travel faster than the speed of light, but space itself expanded much faster than the speed of light during the early 'inflationary' phase of the Big Bang, before 10^{-32} seconds had elapsed and where the early universe grew to enormous size in an unimaginably tiny fraction of a second, going through several phases as shown in Fig.29.

Because of the ongoing inflation of the universe, objects can be more light years away than the universe's age.

We can currently look as far back in time as the cosmic microwave background 380,000 years after the Big Bang (but not with the JWST, as explained below). In future, it may be possible to look back in time even further than that by detecting so-called primordial gravitational waves, which current detectors cannot sense (see our article on Gravitational Waves in the October 2021 issue – siliconchip.au/Article/15063).

There are also density waves, like shock waves, which correspond to the regions of differing matter density in the universe that led to the formation of stars and galaxies.

A consequence of the Big Bang is that all parts of the universe are moving away from each other, like dots painted on the surface of a balloon as it is inflated. We see these objects as they were long ago, not as they are now, because of the time it takes light to travel to us.

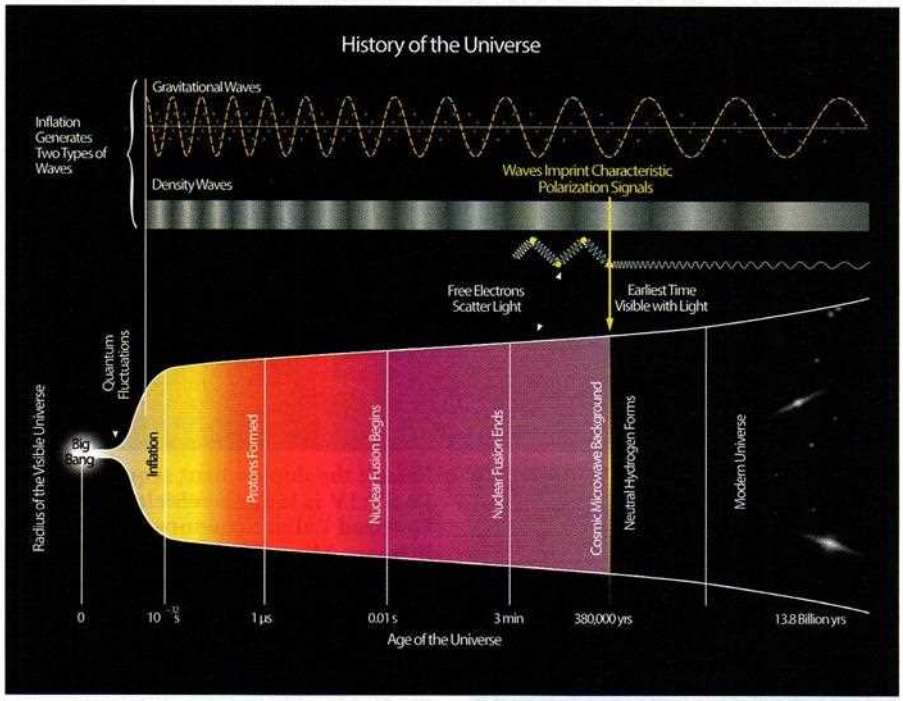
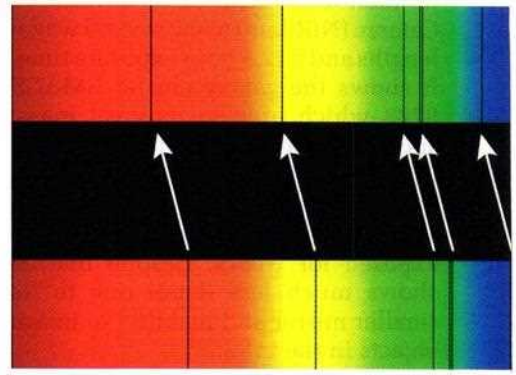


Fig.29: a timeline of events during the universe's formation, showing how the radius of the universe is thought to have changed with time. Note the gravitational and density waves. *Source:* https://w.wiki/5gyk *(CC BY-SA 3.0).*

Redshift

Just as a vehicle-mounted siren appears to rise in frequency as it approaches and falls in frequency as it moves away, so too does light. A light source such as a star or galaxy moving away from us shifts toward a lower frequency which is also a longer wavelength, pushing it toward the red end of the spectrum. This is called redshift. The opposite, blueshift, occurs for objects moving towards us.

In 1929, Edwin Hubble discovered that all galaxies were moving away from us and each other, ie, the



universe was expanding. He saw that the redshift of fainter and presumably more distant galaxies was greater than brighter, closer galaxies. Hence, he concluded that the more distant the galaxy, the faster it is receding and that the universe must be expanding.

The rate at which the universe is expanding is determined by the Hubble constant, which is about 65km/s for every three million light years an object is away from us. One light year is the distance light travels in a year, about 9,461,000,000,000,000km.

It was also concluded that the higher the redshift of a galaxy (the same as saying the more distant it is), the earlier in its life we see it. In other words, we see it the way light first left the object millions or billions of years ago. The object might not even exist now, but we wouldn't know that and would have to wait millions or billions of years to find out.

The redshift can be so far toward and beyond the red end of the spectrum that it is beyond the visible light spectrum, ie, in the infrared.

We can tell how far the light spectrum has been redshifted by reference to specific markers within the spectra corresponding to known molecular and atomic absorption lines. These characteristic spectral patterns correspond to specific elements or compounds – see Fig.30.

In extreme cases, ie, the most distant objects, the entire spectrum becomes invisible as it has entirely shifted into the infrared.

The Big Bang happened 13.8 billion years ago, and the first stars are now believed to have formed 100 million years after the Big Bang and the first galaxies about one billion years after the Big Bang. The JWST seeks to detect some of the very first stars and galaxies.

Redshift is denoted by the letter z, corresponding to the fractional change in wavelength. For example, if light were emitted at 120nm (nanometres) and observed at 150nm, the redshift factor z would be 0.25 (150 ÷ 120 – 1).

While the HST can see objects no further back than 400 million years after the Big Bang (redshift of z ≈ 11.1), JWST can detect objects even earlier at 180 million years after the Big Bang (redshift z ≈ 20).

The earliest stars are now thought to be from 100 to 180 million years after the Big Bang (redshift of z ≈ 30 to z ≈ 20), and the earliest galaxies from 270 million years after the Big Bang (redshift of z ≈ 15).

Imaging in the infrared

The ability to image in the infrared has several advantages plus some challenges. Important advantages are:

1. Being able to see through dust and gas clouds, as they tend to block visible light but are transparent to IR.
2. Being able to see very distant objects where the redshift causes them to be invisible in the visible light spectrum.
3. Infrared radiation is absorbed in Earth's atmosphere, so an IR space telescope can see things that are very difficult or impossible to image from the Earth's surface.
4. Objects such as planets, local asteroids and debris discs around other solar systems being formed emit more strongly in the infrared than in visual wavelengths.

One of the most significant challenges is that the telescope has to be kept as cool as possible because all matter radiates in the infrared in proportion to its temperature.

The colder something is held, the less infrared radiation emanates from it. We all know that metal objects glow when very hot, but you might not realise that they emit light before being heated; we just can't see it because it is infrared.

If the telescope and its instruments were not kept cool, the instruments would not be able to detect infrared radiation from the universe because they would be swamped by radiation from the telescope itself.

The use of infrared telescopes is limited on Earth because water vapour in the atmosphere absorbs infrared radiation. Such telescopes are placed on

Why doesn't JWST have 'selfie' cameras?

The JWST doesn't have any cameras for viewing itself because they would be an unnecessary source of unwanted heat. Heat would be conducted along the connecting wires and struts even if they were turned off. It was a matter that the designers did carefully consider. Also, onboard sensors can detect most malfunctions.

The telescope does have a limited capability to take a selfie of the primary mirror.

A 'selfie' image of the primary mirror of the JWST taken during initial mirror alignment procedures. *Source:* https://blogs.nasa.gov/webb/2022/02/11/photons-received-webb-sees-its-first-star-18-times/

Fig.30: two example spectra with absorption lines; our Sun below and a supercluster of distant galaxies above. The upper absorption lines are all shifted towards the red end of the spectrum due to redshift as the cluster is moving away from us rapidly. *Source:* www.cta-observatory.org/redshift-why-does-distance-matter-to-cta/

Can the JWST be seen with other telescopes?

Researchers at the Virtual Telescope Project (www.virtualtelescope.eu) managed to image the JWST as a single small dot of light.

The JWST imaged with an amateur Planewave 17in (43cm) f/6.8 telescope with a 300s exposure. *Source:* www.virtualtelescope.eu/2022/01/25/james-webb-space-telescope-a-new-image-24-jan-2022/

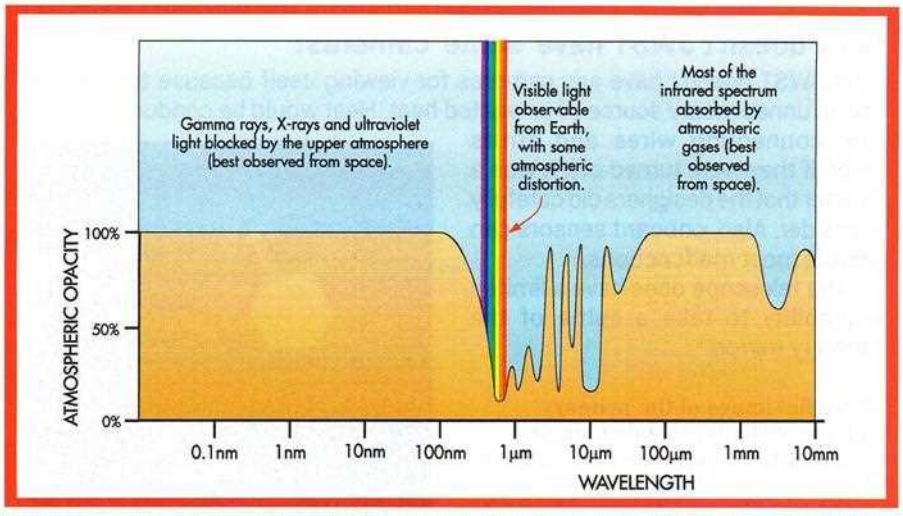


Fig.31: our atmosphere almost completely absorbs infrared energy. That is why infrared observations are best made from space. *Source:* https://w.wiki/5gym

high mountain tops with dry environments or are airborne on aircraft or balloons. Regardless, superior infrared observations can be made from space – see Fig.31.

Looking back further in time

While the JWST looks back in time as far as is possible to see with infrared light, to about 180 million years after the Big Bang, we have looked back further in time using microwaves with the Wilkinson Microwave Anisotropy Probe (WMAP) to about 375,000 years after the Big Bang.

This was a time before star and galaxy formation; microwaves were evidence of the "afterglow" of the Big Bang – see Fig.32.

The time between 375,000 and 400 million years after the Big Bang is known as the "Cosmic Dark Age", as there were (previously) believed to be no stars or other light sources to generate light. In fact, the end of the Cosmic Dark Age at 400 million years is now disputed. The JWST has found galaxies younger than that (see below).

The most distant galaxy

At the time of writing, the most distant and earliest galaxy is believed to be the candidate object named CEERS-93316, discovered using the JWST in July 2022 – see Figs.33 & 34. It is believed to have formed just 235.8 million years after the Big Bang. It was previously believed that the first

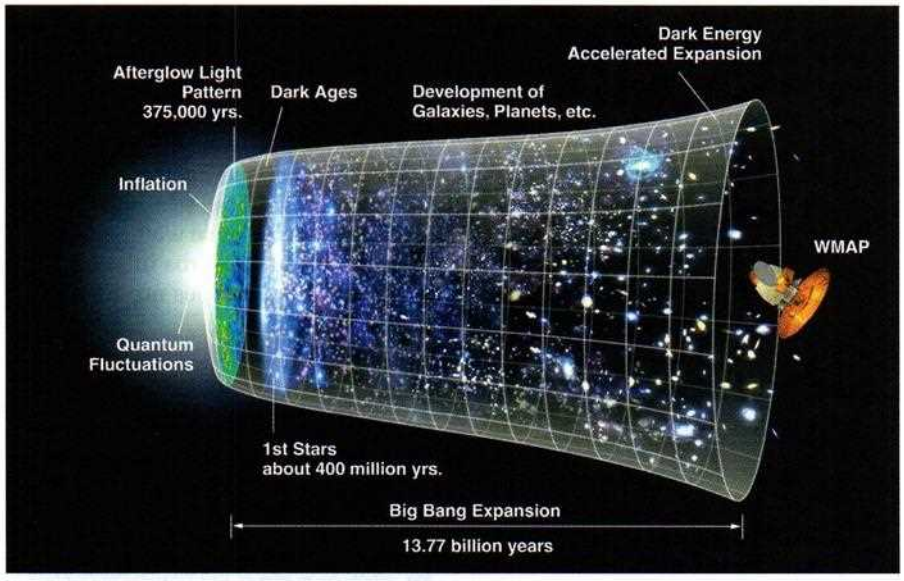


Fig.32: looking back in time with microwaves. The cosmic microwave background was imaged by the Wilkinson Microwave Anisotropy Probe (WMAP) and depicted as the afterglow pattern in this diagram. The JWST sees back in time to the first stars. *Source:* https://map.gsfc.nasa.gov/media/060915/index.html

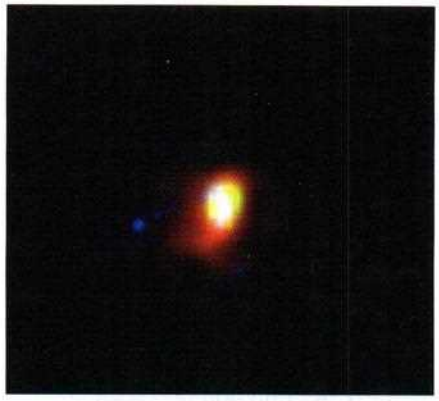


Fig.33: the galaxy CEERS-93316. It mightn't look like much, but it is the most distant object yet observed by the JWST. *Source:* www.ed.ac.uk/news/2022/edinburgh-astronomers-find-most-distant-galaxy

galaxies formed 400 million years after the Big Bang.

Light from this object has travelled for 13.55 billion years, and the distance to the object is 34.68 billion light years due to the universe's expansion. The red shift is $z \approx 16.7$.

Imaging exoplanets

JWST will be able to observe certain young, hot planets via a technique called direct imaging as well as other methods. JWST will also be able to detect oxygen and organic molecules in exoplanet atmospheres, which are possible indicators of life.

Limited ability for service

The JWST was not intended to be serviced. Once its fuel is depleted or there is a major system failure, the mission will be terminated. The minimum planned mission time is five years, so service is not expected to be needed, but compare that to Hubble, which has exceeded its design lifetime by a substantial margin and has been in orbit for 32 years.

But the HST was designed to be serviced and was placed in an orbit accessible by the Space Shuttle.

In contrast, the JWST is in a very hard-to-access orbit. There is no present way to service the JWST, but there are very limited provisions for a possible manned or robotic servicing operation. Details on that are hard to find.

Among these provisions are a refuelling adaptor and, according to Space.com, a docking ring (see their 2007 article at siliconchip.au/link/abgo). Alternatively, the interface ring used to attach the JWST to the Ariane 5

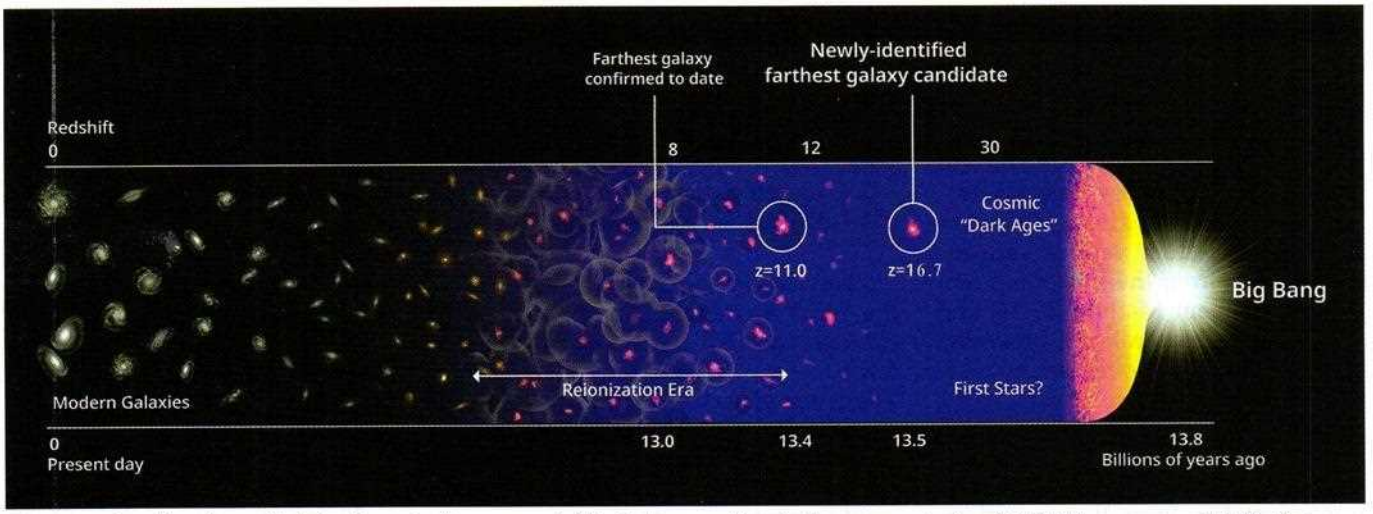


Fig.34: a timeline from the Big Bang to the present. The letter z refers to the amount of redshift. The more redshift, the more distant the object and the older it is. *Source:* https://w.wiki/5gyn

launch vehicle could be used to grapple the spacecraft.

The JWST has been engineered with multiple redundant systems so that if one fails, others can take over, minimising the need for servicing. The goal is for a ten-year lifespan, ie, twice the planned mission duration. Ultimately, if there are no significant failures, the fuel supply for station keeping will be the limiting factor.

Because of an excellent initial rocket burn and trajectory, it used much less fuel for mid-course correction than expected, and it is hoped that there is enough fuel left for perhaps 20 years of operation.

Electrical power

The JWST has a solar array to provide 2kW of electrical power. JWST stores power from the array in lithium-ion batteries, specifically, Enersys ABSL types in an 8S44P (series and parallel) 28V, ~66Ah configuration.

Propulsion & attitude keeping

The propulsion system uses thrusters that run on hydrazine fuel (N_2H_4, 159L tank capacity) with dinitrogen tetroxide oxidiser (N_2O_4, 79.5L tank capacity).

There are four Secondary Combustion Augmented Thrusters (SCATs) in two pairs. One pair was used to propel the JWST into orbit, while the other is for station keeping. It also has eight monopropellant Rocket Engines (MRE-1) – see Fig.35. These use hydrazine decomposition (without oxidiser) and are for attitude control and momentum unloading of the reaction wheels.

Slewing and then pointing the telescope in the desired direction is done

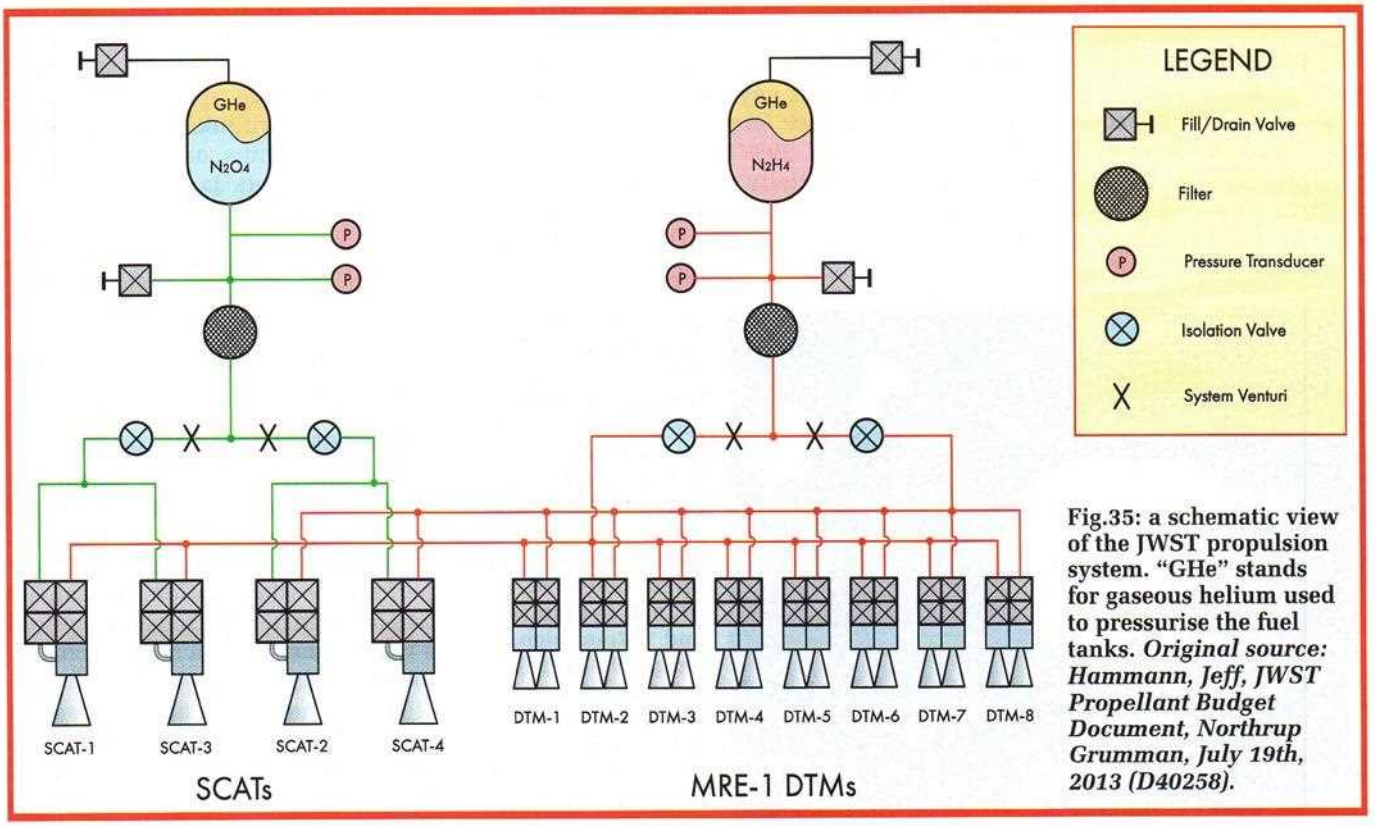


Fig.35: a schematic view of the JWST propulsion system. "GHe" stands for gaseous helium used to pressurise the fuel tanks. *Original source: Hammann, Jeff, JWST Propellant Budget Document, Northrup Grumman, July 19th, 2013 (D40258).*

by the Attitude Control System (ACS) and the JWST Fine Guidance Sensor (FGS). The ACS also is responsible for Delta-V (orbit correction), momentum unloading (see below), antenna pointing, avoiding pointing at the Sun and controlling observatory "safe modes".

The spacecraft flight software receives data from various sensors, instructions from the Integrated Science Instrument Module (ISIM) and JWST ground control and processes them to send data to either the reaction wheels or the thrusters.

The sensors include sun sensors, two star trackers and gyroscopes. The star trackers choose appropriate stars from a catalog, track their positions and compare them with the commanded position.

During exposures (taking pictures), the Fine Guidance System (FGS) observes the guide star and makes measurements every 64ms. That data is sent to the ACS, which corrects any pointing error using reaction wheels and the Fine Steering Mirror (FSM).

Momentum management and reaction wheels

Reaction wheels are used in spacecraft, including the JWST, to control their attitude (orientation with respect to a fixed object). They are essentially motorised flywheels. When the wheel spins up or down, the spacecraft reacts by rotating in the opposite direction. The JWST has six reaction wheels – see Fig.36.

Their use saves spacecraft fuel and they can also be used for tiny and accurate attitude adjustments, more so than rocket thrusters. They can only be used to rotate a spacecraft, not to move it.

Interesting links

1. Build a paper model of the JWST: siliconchip.au/link/abgq
2. Make a model of the JWST mirror: siliconchip.au/link/abgr
3. Links for accessing data from JWST and instrument documentation: siliconchip.au/link/abgs
4. Details of all the deployment operations: siliconchip.au/link/abgt
5. 43-part playlist of time-lapse videos of the JWST being built and tested: siliconchip.au/link/abgp

Photons from the Sun constantly hit the JWST sunshield. Since photons can exert a small force, this causes a force to be applied to the telescope. The centre of pressure of the sunshield is not the same as the centre of mass of the telescope, so this force generates a torque, making the telescope want to rotate.

The reaction wheels counter this rotation. As a result, angular momentum accumulates in the wheels (ie, they keep spinning faster). If this were not corrected, the wheels would exceed their design limits. Therefore, the thrusters are fired about 4-8 times per month to allow the reaction wheels to be spun down. This "momentum unloading" activity takes several hours.

The JWST has a "momentum flap", also known as a "trim flap", to somewhat minimise the rotation due to photon pressure, saving fuel.

What can JWST image?

Every six months, the JWST can image almost anything in the celestial sphere as it orbits the Sun and the Earth. At any one instant, however, it can see anything with a 50° field of view. 39% of the celestial sphere is potentially accessible to it at once.

The only areas permanently inaccessible are imaging of the Sun, Mercury, Venus, Earth and Moon as these are too hot and would overload its sensors, possibly damaging or destroying them.

False image colours

Images in visible light have the traditional colours of the visible light spectrum that we are used to, but pictures from the JWST are also coloured, even though they were taken in the infrared.

Beyond the visible light spectrum, colour is meaningless; however, adding colour to images helps us interpret them, so, like visible light, colour in infrared images is based on the wavelength of the light detected.

Colour is arbitrarily assigned to the various infrared wavelengths to convey additional information to us; otherwise, the images would be all in greyscale and only show intensity information.

Data and comms

Data from the JWST is sent to the ground via NASA's Deep Space Network. The telescope can downlink a minimum of 57.2GB of data daily at 28Mbit/s. It has a solid-state data recorder to store up to 65GB of science data. Downlinks occur twice per day for four hours, and up to 28.6GB of recorded data is transmitted per downlink period.

Comms occur over Ka-band (27-40GHz) for the high-rate downlink of data and telemetry, and S-band (2-4GHz), which is used for command uplink, low-rate telemetry downlink and ranging.

Micrometeroroid impacts

As expected, the JWST mirror has suffered at least 19 micrometeoroid impacts at the time of writing, but these have not caused any significant performance degradation. One impact was larger than expected and required a readjustment of the mirror actuator to compensate for the damage.

When the JWST passes through high-risk areas, its mirror will be turned away from the direction of travel. SC

Fig.36: a model RSI 50-220/451 reaction wheel, similar or the same as used on the JWST and built by Rockwell Collins Deutschland GmbH (formerly Teldix). It features integrated electronics, spins at up to 4500 RPM, is 347mm in diameter and 124mm high, weighs 9.5kg, runs on 100V DC and consumes under 20W. *Source: https://artes.esa.int/projects/htmod2*

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Music sensor can trigger lights to the beat!

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This kit includes 5m of RGB strip lighting, power supply and controller unit allowing you to create colourful lighting effects around your home. Music sensor input allows the lighting to trigger to music being played in the room. Works with Alexa and Google Assistant. 60 LEDs per metre.

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X 4201 5 Dioptre
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D 0515A*

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M 8195B

NEW!

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M 8197

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Ultra slim 75mm profile with full current discharge capability and a 5 year warranty.

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X 0604C

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N 2099A

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Ensure your battery doesn't go flat with this handy Bluetooth® battery monitor. Provides live feedback on your vehicle or auxiliary battery, plus handy long term stats.

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BONUS! Z 6439B micro:bit board. Valued at $36.50

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B 0012

Things can get messy when you're prototyping a design on a breadboard but you don't want to make a mistake hooking up the power supply! This Dual-Channel Breadboard PSU is the perfect solution. It plugs straight into a breadboard's power rails, has two adjustable current-limited outputs and can run from different power sources. It has already become an indispensable part of our workbench.

We do a lot of prototyping on breadboards. It's the easiest way to test ideas, especially if you need to tweak and modify a circuit configuration. Jumper wires make it very easy to wire up a circuit and change it on a solderless breadboard.

While you can get compact power supply modules that plug straight into a breadboard and provide 5V and 3.3V rails, like Jaycar Cat XC4606 and Altronics Cat Z6355, they have their drawbacks. The main problems are that they only offer one voltage at a time and lack the flexibility and current limiting features of a bench power supply.

So we decided to design a low-cost, easy-to-build replacement incorporating the most important features of a bench supply.

The result is a Breadboard PSU that's versatile yet straightforward. It plugs directly into a breadboard's power rails at one end, like the simpler supplies described above, but it has two independent outputs.

We have published a similar design called the Arduino-based Power Supply (February 2021; siliconchip.au/Article/14741), a compact solution for a home workshop. Like this Breadboard PSU, it provides up to 14V output at up to 1A, although it only has one output.

As the Arduino-based Power Supply is controlled by a computer, it can be tucked away. Its controls and display are displayed on the computer screen, so it does not take up any more valuable workbench space.

But there is nothing quite so tactile as being able to adjust a couple of knobs to dial in voltage and current settings while you're testing a prototype, and that is how the Breadboard PSU works. If you're working close-up with the breadboard, having the supply controls nearby is convenient, and the PSU doesn't make the whole breadboard set-up much bigger.

Two independent output channels

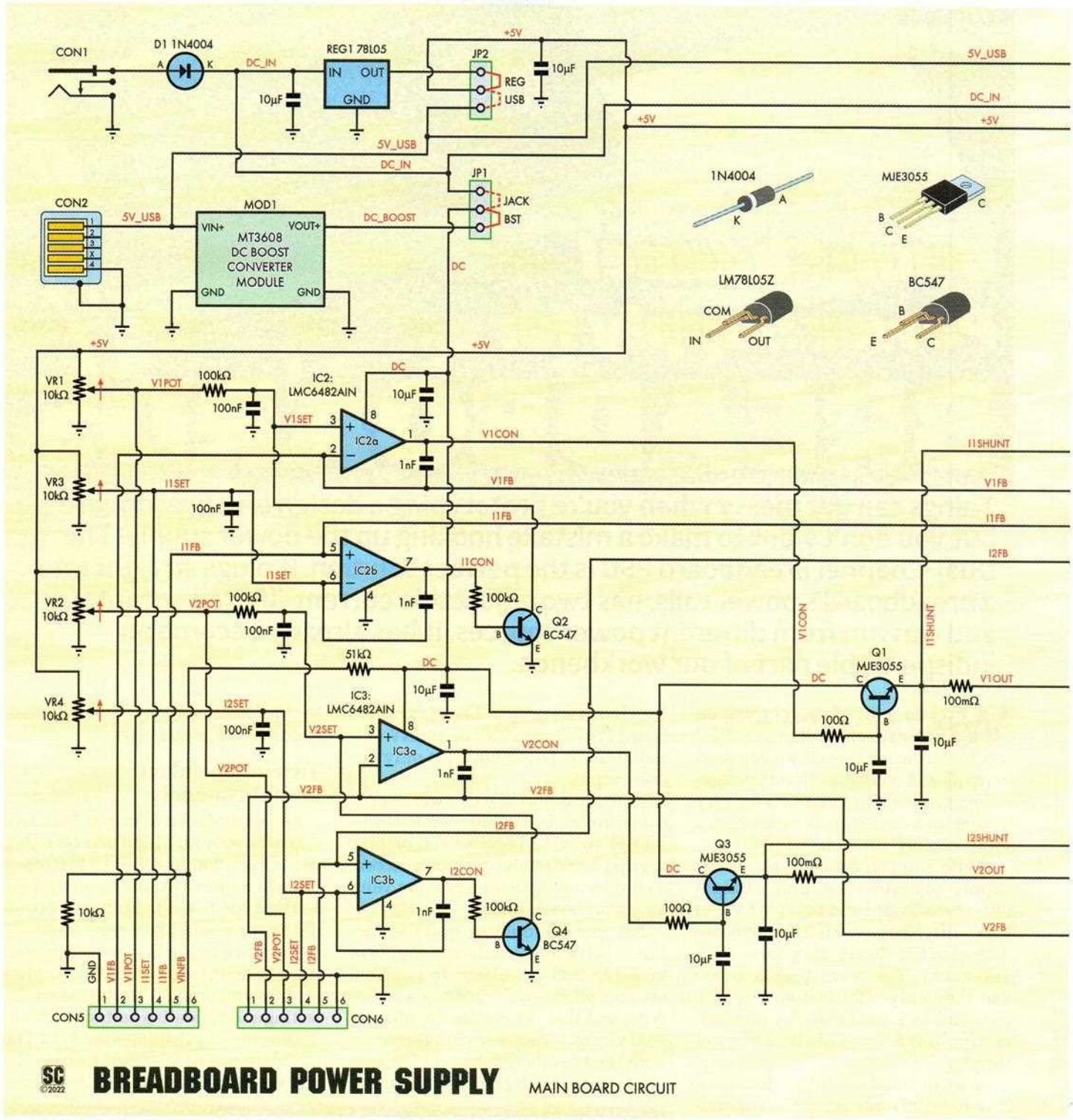
Most breadboards have at least two sets of supply rails, one pair on either side. Given that, and the fact that many circuits require two voltages (eg, 3.3V & 5V or 5V & 12V), adding a second channel seemed like a great idea.

Even just using the two outputs as independent, current-limited supplies at the same voltage can be handy for testing and validating parts of a circuit.

Despite duplicating much of the circuitry, we've managed to keep the end result compact. The basic version

Features & Specifications

- Two independent channels
- Each channel delivers 0-14V/0-1A (depending on input supply & load)
- Runs from 7-15V DC or USB 5V DC
- Plugs straight into breadboard power rails
- Four potentiometers provide all controls
- Optional metering add-on described on page 40 (shown above)
- Transient load regulation: <80mV DC + 350mV AC, 0-1A
- Transient settling time: 300µs, 0-1A



BREADBOARD POWER SUPPLY MAIN BOARD CIRCUIT

doesn't even have a display; it just has four knobs to dial in the voltage and current limit on each of the two channels.

It is certainly usable on its own, but there are evident benefits to being able to see the output voltages and currents as you work on your prototype. Later, we will present a neat little display module that not only provides readouts for the Breadboard PSU. It even has extra measuring channels to help you see what else is happening on your breadboard!

Circuit operation

For the most part, the two channels of the Breadboard PSU have identical circuits that work independently. They are supplemented by some common supply circuitry, as shown in Fig.1, the full circuit diagram.

You might notice that there are no regulator ICs in the main part of the circuit, at lower left. Instead, like the earlier Arduino PSU, the two outputs have their voltage regulated by op amps controlling NPN emitter-follower transistors (Q1 & Q3). The op amps use negative feedback to adjust the transistor base voltages to maintain the desired output voltages.

This method of regulation can be

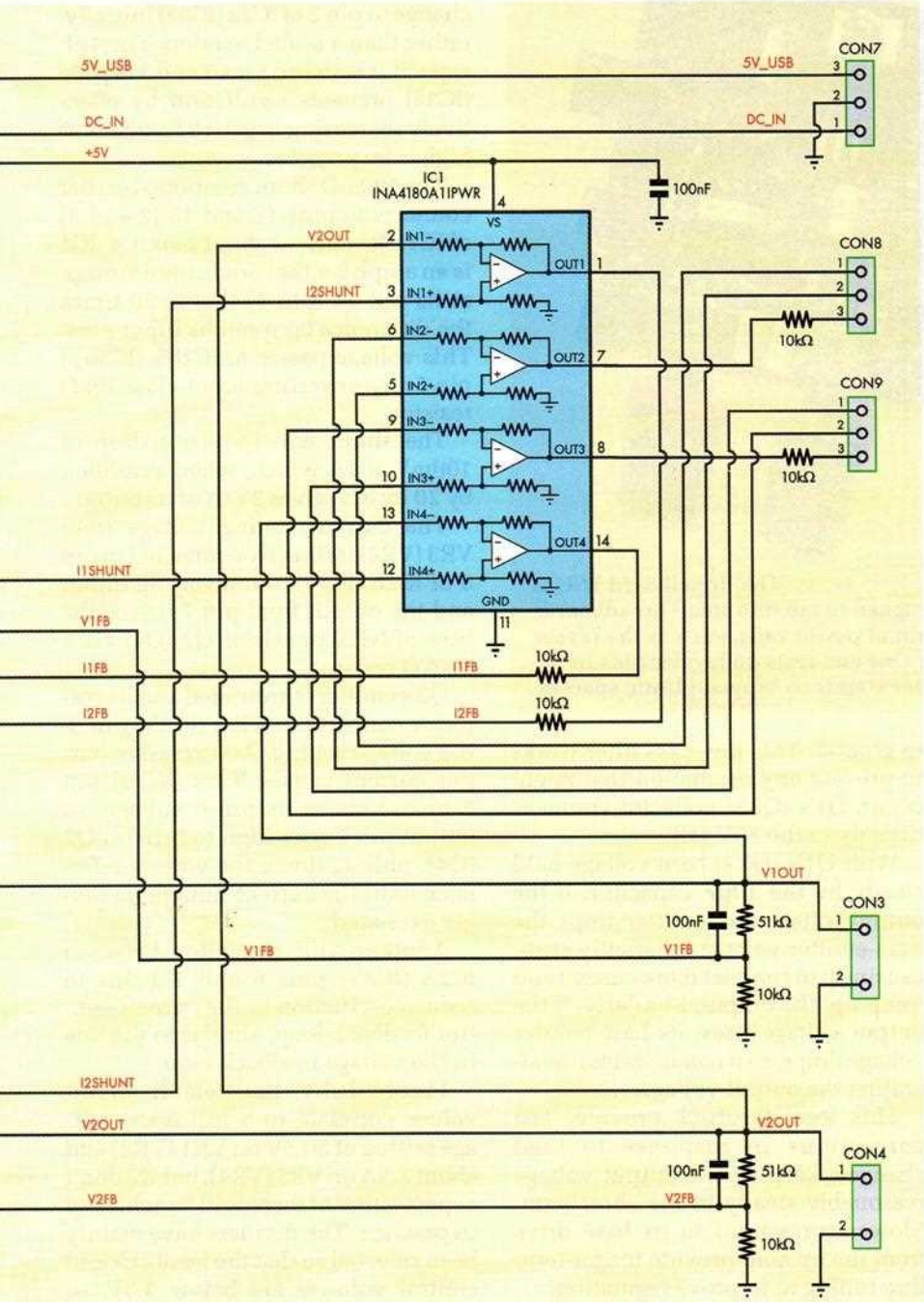


Fig.1: the Breadboard PSU shares some circuitry with the Arduino Programmable Power Supply but with no microcontroller in sight. Instead, four potentiometers provide control of two independent current-limited adjustable supplies.

a bit tricky due to the need for it to respond fast to changes in output load while at the same time, needing stability to avoid oscillation. Luckily, by using NPN emitter-followers, we avoid a large phase shift and gain a great deal of 'local feedback', so the op amps only need to make minor adjustments. More on that local feedback later.

As the supply is intended to be flexible, there are two different ways to power it. We'll refer to the higher of these as 15V but its absolute maximum is 16V, the highest voltage that all circuit components can tolerate. Apart from this, its exact value is not critical and we expect users will stick to around 12-15V DC, as supplies delivering that range of voltages are pretty common.

Since the highest possible output voltage is around 2V below this rail, even a 9V battery is a valid option if you only need voltages up to about 5V. For example, if you are working primarily with microcontrollers.

Breadboard power modules like this are available from Jaycar and Altronics. They are inexpensive, convenient and can provide 5V and 3.3V rails as set by a switch, but they only supply one voltage at a time and don't have adjustable voltages or current limiting.

A 5V rail also exists in the circuit for components that cannot handle 15V. JP1 and JP2 provide the means to configure the sources of the 15V and 5V rails, respectively, and are derived from DC input jack CON1 and USB socket CON2.

The incoming DC voltage at CON1 passes through reverse-polarity protection diode D1 to one side of JP1, allowing direct use of the incoming voltage for the 15V rail. The incoming DC at CON1 also feeds 78L05 linear regulator REG1, accompanied by an input bypass capacitor to produce a 5V rail, which goes to one side of JP2.

With JP1 and JP2 set to the "REG" and "JACK" positions, the power from CON1 supplies all the power rails on the Breadboard PSU.

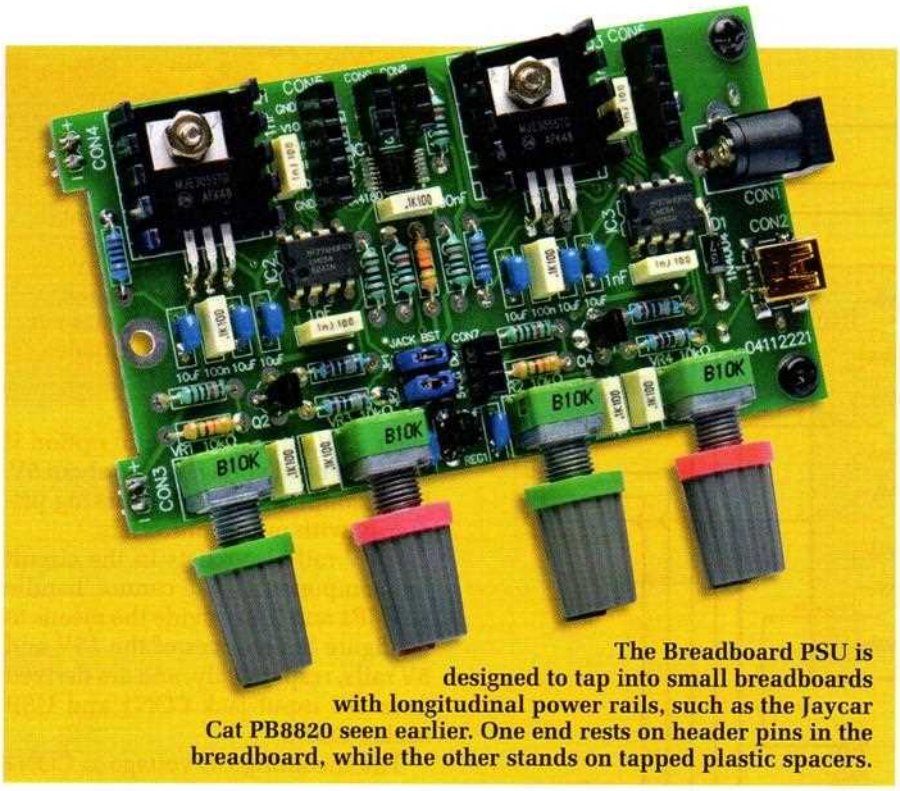
When JP1 and JP2 are set to the alternative "BST" and "USB" positions, the 15V rail is derived from MOD1, an MT3608 boost module, which is supplied by 5V from the USB socket. The boost module has an adjustable output which must not be set any higher than 16V.

Other components common to the two supplies are a 51kΩ/10kΩ divider which provides a scaled version of the 15V DC rail to a pin on CON5 for external monitoring.

A four-channel INA4180A1 current shunt monitor (IC1) and its 100nF bypass capacitor are also shared between the two channels. It is powered from the 5V rail and used to monitor the output current of each channel plus optionally two other currents across pairs of points on the breadboard.

Dual independent regulators

The remaining circuitry is independently allocated to one of the two



The Breadboard PSU is designed to tap into small breadboards with longitudinal power rails, such as the Jaycar Cat PB8820 seen earlier. One end rests on header pins in the breadboard, while the other stands on tapped plastic spacers.

channels and identical between the two. Therefore, we'll describe the function of one channel, with designations in brackets to indicate the equivalent part for the other channel.

10kΩ potentiometers VR1 (VR2) and VR3 (VR4) are wired across the 5V rail to set the voltage and current targets, respectively.

The control voltage from VR1 (VR2) passes through a 100kΩ resistor and is filtered by a 100nF capacitor to reject noise, while the current control voltage goes directly to its own 100nF capacitor. These feed pins 3 and 6 of dual rail-to-rail op amp IC2 (IC3), respectively.

The 16V supply limit of the op amps dictates the maximum of 16V the design can handle.

IC2 (IC3) has a 10µF capacitor between its pin 4 and 8 supply pins, as its outputs can be expected to deliver a reasonable amount of current in sympathy with the PSU's load. Its supply comes from the 15V rail and circuit ground.

The voltage at pin 3 is compared with that at pin 2, which comes from a 51kΩ/10kΩ divider across output connector CON3 (CON4). This is fed from the emitter of MJE3055 NPN power transistor Q1 (Q3) via a 100mΩ current-sense resistor.

Q1's (Q3's) base is fed current from IC2's (IC3's) pin 1 output via a 100Ω resistor, filtered by a 10µF capacitor to ground. This low-pass filter works to prevent any oscillation that might occur. Q1's (Q3's) collector connects directly to the 15V rail.

With Q1's (Q3's) base voltage held steady by the 10µF capacitor, if the output voltage at its emitter drops, the base-emitter voltage inherently rises, causing it to conduct more current and 'prop up' the output. Similarly, if the output voltage rises, its base-emitter voltage drops, so it conducts less, moderating the output voltage.

This local feedback provides fast corrections in response to load changes, keeping the output voltage reasonably steady in the short term. Slower corrections to its base drive from the op amp provide longer-term fine-tuning to improve regulation.

IC2a (IC3a) effectively tries to keep pins 2 and 3 at the same voltage by changing its output at pin 1. The voltage applied to CON3 (CON4) is thus a scaled version of the voltage on IC2a's (IC3a's) pin 3 with a low source impedance, forming the voltage control portion of the circuit.

For the most part, the output voltage is proportional (as per the 51kΩ/10kΩ divider) to the voltage set by the voltage at the wiper of VR1 (VR2), but it can vary, as we shall see shortly.

The 100nF capacitor across the 51kΩ feedback resistor helps the circuit respond quickly to changes by applying the full output voltage change to pin 2 of IC2a (IC3a) initially, rather than a scaled version. The 1nF capacitor between pins 1 and 2 of IC2a (IC3a) prevents oscillation by effectively increasing negative feedback at higher frequencies.

The 100mΩ shunt mentioned earlier connects to pins 12 and 13 (2 and 3) of IC1, the current shunt monitor. IC1 is an amplifier that produces a voltage at its pin 14 (pin 1) that is 20 times the difference between its input pins. This voltage passes to IC2b's (IC3b's) pin 5 non-inverting input via a 10kΩ resistor.

The shunt will induce a drop of 100mV at 1A which, when amplified by 20 by IC1, gives 2V/A at its output.

The current setting voltage from VR3 (VR4) is directly connected to pin 6 of IC2b (IC3b), the inverting input, and the output from pin 7 drives the base of NPN transistor Q2 (Q4) via a 100kΩ resistor.

Q2's emitter is grounded and its collector connects to IC2's (IC3's) pin 3, the voltage setting. An excessive output current causes IC2's (IC3's) pin 5 to rise above its pin 6 voltage, so output pin 7 goes high to turn on Q2 (Q4), pulling down the voltage reference until the current limit is no longer exceeded.

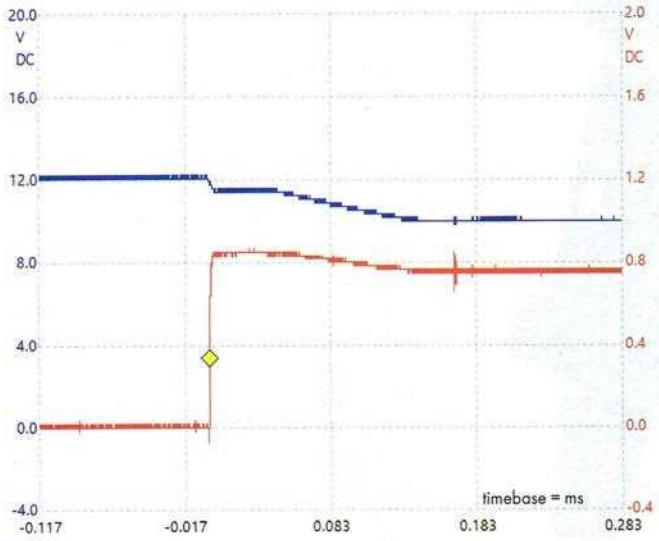
Another 1nF capacitor between IC2's (IC3's) pins 6 and 7 helps to reduce oscillation in the current control feedback loop, similar to the one in the voltage feedback loop.

Theoretically, the default circuit values correlate to a full-scale voltage setting of 30.5V on VR1 (VR2) and about 2.5A on VR3 (VR4), but we don't expect either of these will be achieved in practice. The dividers have mainly been selected so that the feedback and control voltages are below 3.3V, so an external monitoring circuit with a 0-3.3V input range can be used.

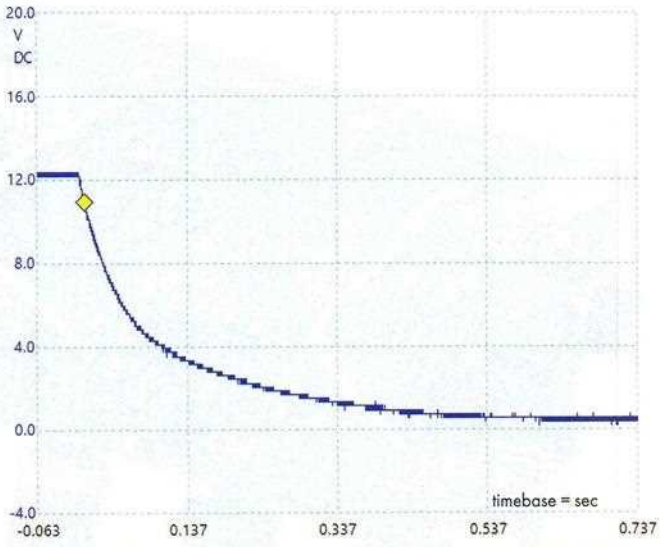
If REG1 were replaced with a pin-compatible 3.3V type (that can withstand an input of at least 16V), the maximum voltage and current settings would be 20V and 1.65A. This would have the advantage of making the controls less sensitive, so accurate adjustments could be made more easily.

Supply options

Feeding in 12-15V DC to CON1 will give the best results, as the 5V output of REG1 will be better regulated than the 5V DC from a USB power supply. While the USB option is convenient,



Scope 1: the response to a load change that triggers current limiting is about as fast as possible given the size of the output capacitor. The 23.5Ω load brings the output voltage down from 12V to 10V at around 400mA.



Scope 2: the slowest response under any situation is shown here, where the output voltage is instantaneously set to 0V with no load. The drop rate is limited by the output capacitor discharging through the output voltage divider.

the boost module could impose a high current draw on the USB supply, which might cause unexpected glitches if it is overloaded.

If you only ever plan to feed in power via CON1, you could omit the USB socket and MOD1 and hard-wire the two jumpers.

The remaining connectors, CON5-CON9, are not needed when the Breadboard PSU is used in its standalone configuration, but can be used to connect to the display daughterboard, to be described on page 40.

If fitting these connectors, use header sockets (they will be included as part of the kit). These not only match up with the headers on the display board, but they also make it easy to use standard breadboard jumper wires to connect these points to your breadboard circuit.

If you wish to tap into them for other purposes, CON5 and CON6 connect to most of the low-voltage signals mentioned earlier. CON7 provides breakouts for the incoming supplies from CON1 and CON2. CON8 and CON9 connect to the two spare current shunt monitor channels on IC1.

Performance

As the Breadboard PSU is based heavily on the circuit of the Arduino PSU, we knew it would work well. Still, we have produced a few scope grabs to give you an idea of what to expect.

The response to a current limiting event is critical to any bench supply's performance. Scope 1 shows the Breadboard PSU's output using our Arduino Programmable Load (June 2022; siliconchip.au/Article/15341) to apply a step load change from an open circuit to 23.5Ω, with an initial voltage of 12V.

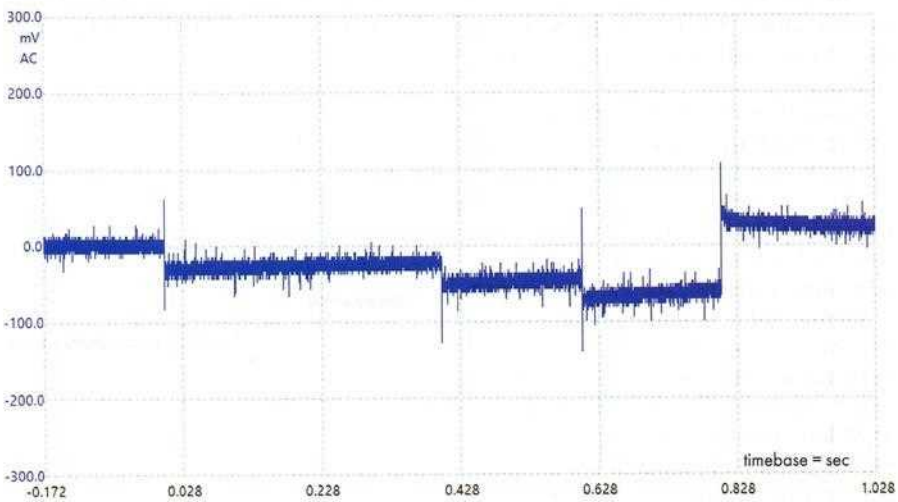
The blue trace is the voltage and the red trace is the current, peaking at around 500mA. As you can see, the Breadboard PSU starts reacting almost immediately and has settled to the new operating point after about 150µs.

Note that the time constant of the 10µF output capacitor into a 23.5Ω load is about the same duration, so most of the delay is actually due to the output capacitance discharging.

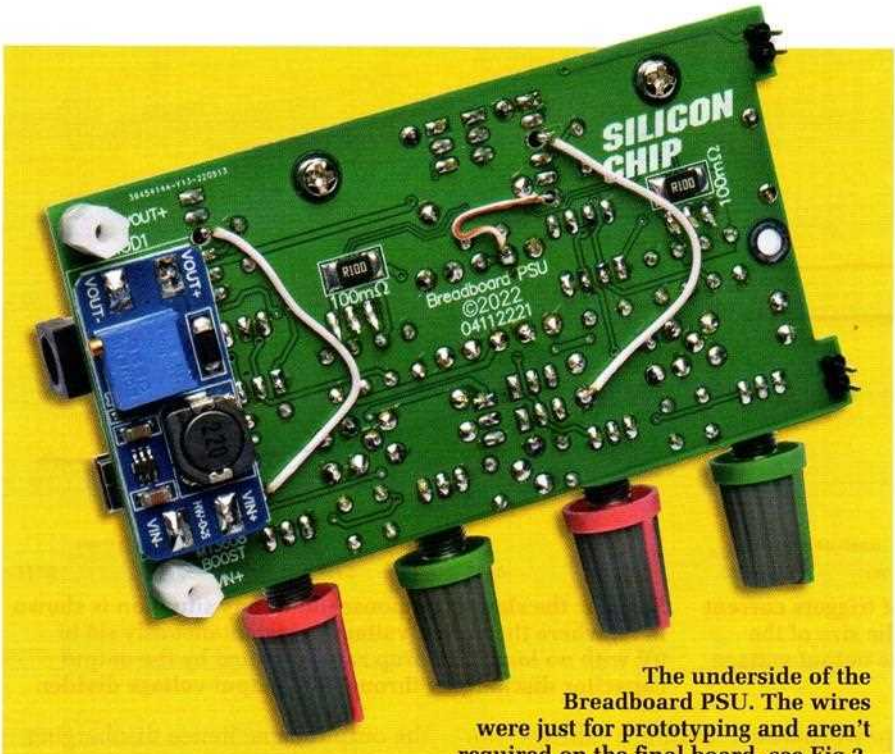
Scope 2 shows a step change in the voltage setting from 12V down to 0V (applied by shorting the VR1 wiper to ground). Here, the output voltage takes half a second to decay due to the 10µF capacitor only being able to discharge through the 51kΩ/10kΩ divider.

Of course, any load impedance will cause this to happen much quicker. And it's doubtful that you'll be able to wind the potentiometer down any faster than that anyway.

Transient response is an important parameter for a regulator since it shows how much it will allow the voltage to vary if the load impedance



Scope 3: this scope grab shows a series of load changes from 250mA to 500mA to 750mA to 1A and back to 250mA, with the worst deviation being under 100mV. We made these measurements directly at the output of the PSU. In practice, when using a breadboard, the variation is about three times greater due to the resistance of the breadboard conductors.



The underside of the Breadboard PSU. The wires were just for prototyping and aren't required on the final board, see Fig.2.

changes fast. Scope 3 shows how the output voltage shifts with a series of load changes from 250mA to 500mA to 750mA to 1A and back to 250mA. As you can see, the change in output voltage is small, well under 100mA at 1A compared to no load.

Scope 4 shows a close-up of the transition from 250mA to 500mA in Scope 3. There are brief spikes of +300/–375mV, but it quickly settles to a steady voltage after about 300µs.

Construction

The Breadboard PSU is built on a double-sided PCB coded 04112221 that measures 99 x 54mm, as shown in Fig.2.

Apart from the USB socket (CON2) and the current shunts, all parts can be through-hole types. It could have been smaller if we'd used more surface-mounting parts, but we would still need to leave room for the potentiometers and heatsinks for the transistors.

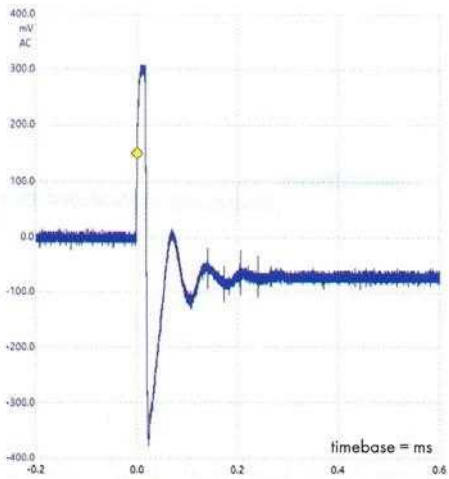
While this project is useful for beginners, constructors will need reasonable soldering skills as most shunt monitor ICs are only available as SMDs, and quad shunt monitor IC1 has fairly closely-spaced leads. Still, it is not that hard to solder with the right tools, a gentle touch and a bit of patience.

We've designed the PCB to accept either through-hole or surface mounting capacitors. So, if you have suitable SMD capacitors, you should fit them along with the other surface mounting parts.

While Fig.2 shows SMD capacitors, our photos reveal we built the prototype with through-hole types. Note that SMD ceramics are usually cheaper than equivalent through-hole caps.

We've extended the pads for the smaller SMD parts to ease assembly. You might get away with simply using a fine-tipped iron, but flux and solder wicking braid will definitely help.

Start with IC1, which has the smallest leads of any of the SMDs. Apply flux to its PCB pads and align the part,



Scope 4: a close-up of the 250mA-500mA transition in Scope 3. There is a bit of overshoot, but it's close to being symmetrical.

checking that the pin 1 marking dots on the part and silkscreen line up. Tack one lead, then gently solder the remaining pins if all is still aligned (use a magnifier to check).

The solder fillets should form easily if you have the right amount of solder and flux. Use the braid to wick up any excess solder that might form bridges between the pins.

CON2 is a surface-mounting USB socket that locks into place with tabs on its underside. Apply flux and carefully solder the two longer pads for power. After that, solder the larger mechanical tabs on the sides of the socket.

The two current shunt resistors are on the reverse of the PCB. Align them within their pads and tack one lead. Adjust the position so that the part is squarely within the silkscreen markings. Then solder the other lead and refresh the first lead if necessary.

Fit the capacitors now if you are using SMD parts. There are three different values and they are all spread around the PCB. Work with one value at a time to avoid mixing them up.

At this point, clean up any excess flux using an appropriate solvent. Be sure to let it dry thoroughly as many such solvents can be flammable.

A good strategy for the remaining parts is to work from the lowest profile components up. Start with the resistors, as they are all mounted flat against the PCB. There are 16 around the PCB; check the silkscreen values against the resistors before soldering. A multimeter is the most reliable way to check the values as the colour markings can sometimes be ambiguous.

Fit the solitary diode D1 next. It is installed near the USB socket and should have its cathode band close to the USB socket. If using through-hole capacitors, fit them next, checking the silkscreen marking against the part marking.

Then install the two op amps. Their pin 1 markings should align with the silkscreen and face to the left of the PCB. You could use sockets, although a socket for IC2 might foul the heatsink for Q1; check first before fitting it. It's generally acceptable to solder them directly to the PCB as you should not need to swap them unless they are faulty, which is unlikely.

There are three TO-92 parts; the two smaller transistors, Q2 and Q4, and voltage regulator REG1. Solder them

in now, making sure to orientate them correctly and don't get them mixed up.

Fit the various headers and jumpers next, but leave CON3 and CON4 to last as they are fitted under the PCB. Check Fig.2 and our photos to see what goes where.

Use three-way headers for the two three-way jumpers, JP1 and JP2. Slot them in place, solder one pin and check that the pins are perpendicular to the PCB surface before soldering the remaining pins. Leave the jumper shunts off until testing has been completed.

The remaining connectors on the top of the PCB (CON5-CON9) are all SIL socket types. It's even more critical to mount them perpendicular to the PCB as they are designed to plug into a second PCB mounted above.

The two larger transistors, Q1 and Q3, need heatsinks. Bend the leads back around 7mm from the body and thread the leads into the PCB holes. Slip the heatsinks in behind the transistors and secure both the transistor and heatsink to the PCB with an 8mm M3 screw on each.

A thin layer of thermal paste on the underside of the transistor tabs is optional, but will help with heat transfer. Add the washer and tighten the nut firmly to position the transistor and heatsink neatly and squarely. Then you can solder and trim the leads.

The remaining larger parts on the top of the PCB should be easy enough; just take care that they are neat. CON1 is adjacent to the CON2 USB socket and the four potentiometers are along one edge of the PCB.

You can fit the knobs now. For splined shafts, dial the potentiometers to their midpoints so that the slot is horizontal. Push on the knob so that the indicator points straight up, also at its midpoint. Then wind the knob anti-clockwise to its minimum position, so it is safe for testing.

We've used red knobs for the current limiting pots (VR3 and VR4) and green knobs (VR1 and VR2) for the voltage setting. Our kits will offer that option and other colour combinations; you can choose whichever you prefer.

Fit the tapped spacers now as these form the legs at one end of the Breadboard PSU and will show you how much clearance you have to mount MOD1.

MOD1 is mounted to the underside of the PCB near CON1 and CON2.

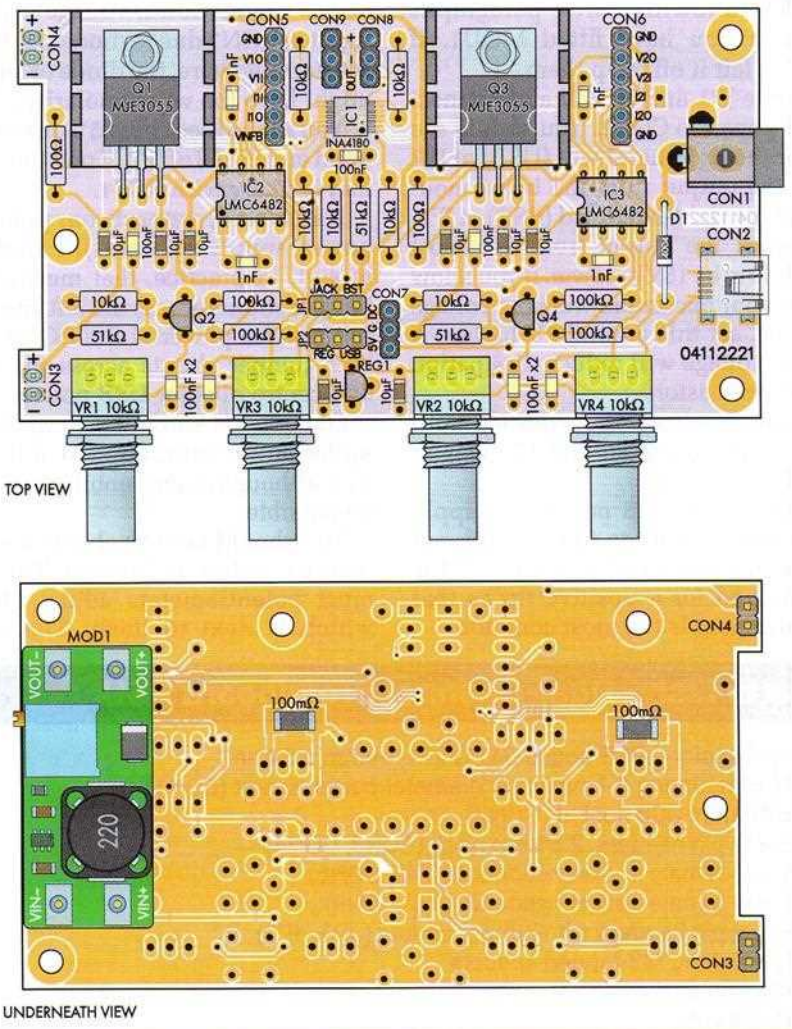


Fig.2: the Breadboard PSU is meant to be compact, so the PCB is pretty packed with components. CON3 and CON4 are fitted under the PCB to connect directly to a breadboard, while the two current-measuring resistors and boost module MOD1 are also on the underside. CON5-CON9 are mainly for fitting the display module. You can omit MOD1 and CON2 if you only plan to use the DC input at CON1.

Since it covers the solder pads for some top-side components, ensure you haven't missed any parts. Trim any leads in that area short, so there is ample clearance.

Orientate the module according to the VIN and VOUT markings on the PCB. Check the polarity too, as we have seen some variants of the MT3608 modules that have the connections reversed.

Then solder it in place using short lead off-cuts through the pads on both boards. Make sure it doesn't protrude further than the spacers; otherwise, it will carry the weight at this end of the PCB.

Also make sure that the underside of the module is not shorting against any leads, then trim the leads that are holding the module.

Finally, fit CON3 and CON4. These can be aligned by pushing the header pins into the breadboard's power rail and then resting the Breadboard PSU PCB in place. We've aligned the positive pins with the red markings on the breadboard. Push everything down flat and then solder the ends of the header pins from above.

Testing

It's easy to run a few tests to verify everything is in order. You'll need a multimeter to measure a few different voltages for testing. All are referred to ground; the shell of CON2 (the mini USB socket) or pin 4 of IC2 or IC3 are

good places to make this connection.

The following three paragraphs assume you have fitted MOD1. If you've left it off, skip them.

Leave JP1 and JP2 off and connect USB power to CON2. You should see 5V at the right-hand end (USB) of JP2 and the output from the boost module at the right-hand end (BST) of JP1.

Adjust the output from the boost module to be 15V or lower. If you know what your maximum working voltage will be, set this around 2V higher. A lower voltage will reduce dissipation in the transistors.

If you don't see the expected voltages, then check around CON2 and MOD1.

Disconnect USB power and apply a suitable supply to CON1. This can be anything from 7V to 15V; CON1 is configured for a positive tip as that arrangement is the most common.

The left-hand end of JP1 (JACK) will have a slightly lower voltage than the input at CON1 due to diode D1. If you see nothing there, the diode or supply might have the wrong polarity.

You should see about 5V on the left-hand end (REG) of JP2. If not, the problem is likely with REG1.

If all is well, connect your preferred power supply and set JP1 and JP2 to suit. In practice, that means both jumper shunts across the left and centre pins for power at the DC jack, or both jumper shunts across the right and centre pins for USB power.

Our photos show the jumpers set up for power being applied at the DC jack, although other combinations may be possible.

You should now be able to test the outputs with a multimeter. The leftmost potentiometers adjust CON3, which is next to them. The other potentiometers adjust CON4.

Move VR2 and VR4 (the current adjust potentiometers) slightly above their lowest position; otherwise, the output is completely shut off. Then slowly increase VR1 and VR3 and check that the voltage changes. The maximum voltage will be reached well before the clockwise position on the potentiometers and will be around 1V below the voltage selected by JP1.

Using it

Once it's plugged into a breadboard, there's not much more to using the Breadboard PSU. Use the potentiometers to adjust the voltages and current limits as needed.

With legs fitted at the end near CON1 and CON2, the Breadboard PSU rests on CON3 and CON4 on a breadboard at the other end. It's designed to be used more or less in the raw state.

If you don't plan to fit the display, you could use extra tapped spacers to mount a sheet of card or plastic above the exposed components for protection.

The transistors operate in linear mode, so they will dissipate quite a bit of power, depending on the settings and supply voltage. If the Breadboard PSU is current limiting into a short circuit, the dissipation will be at its highest.

The provided heatsinks are suitable for up to a few watts, so with a 15V supply, you can set the current limit up to around 200mA without worrying about overheating the transistors. Even at higher dissipation levels, as long as you monitor the current and switch off the supply if it's drawing more than expected, it should survive brief overloads.

For higher currents, especially if you only need much lower voltages, you should consider a lower input voltage to reduce transistor dissipation.

As we mentioned earlier, we have also designed an add-on display module, as shown in the lead photo. It provides readouts of the set and actual currents and voltages. Its operation and construction are shown in detail starting on page 40 of this issue.

The display module can also estimate transistor dissipation by monitoring the voltages and currents, so it can help avoid situations that could overheat the transistors. SC

Parts List – Dual-Channel Breadboard PSU

1 double-sided PCB coded 04112221, 99mm x 54mm
1 PCB-mounting 2.1mm inner diameter barrel socket (CON1)
1 SMD mini-USB socket (CON2)
2 2-way pin headers, 2.54mm pitch (CON3, CON4)
2 6-way female socket headers (CON5, CON6)
3 3-way female socket header (CON7-CON9)
2 3-way pin headers with jumper shunts (JP1, JP2)
2 12mm-long M3-tapped spacers
4 M3 × 8mm machine screws
2 M3 hex nuts
2 M3 shakeproof washers
2 small TO-220 finned heatsinks (no larger than 20 × 20 × 10mm)
1 MT3608 boost module (MOD1) [SC4437]
4 10kΩ 9mm linear potentiometer and knobs to suit (VR1-VR4) [Jaycar RP8510 & HK773x]
4 short component lead off-cuts or pieces of wire (for mounting MOD1)

Semiconductors
1 INA4180A1IPWR quad current shunt monitor, TSSOP-14 (IC1)
2 LMC6482 dual rail-to-rail CMOS op amps, DIP-8 (IC2, IC3)
1 1N4004 400V 1A diode (D1)
2 MJE3055 60V 10A NPN transistors, TO-220 (Q1, Q3) [Jaycar ZT2280]
2 BC547 45V 100mA NPN transistors, TO-92 (Q2,Q4) [Jaycar ZT2152]
1 78L05 5V 100mA linear regulator, TO-92 (REG1) [Jaycar ZV1539]

Capacitors *(all SMD M3216/1206 X5R/X7R or MKT/ceramic radial)*
8 10µF 16V
7 100nF 50V
4 1nF 50V

Resistors *(all ¼W axial 1% metal film except as noted)*
4 100kΩ 3 51kΩ 7 10kΩ 2 100Ω
2 100mΩ M6432/2512 1W SMD

SC6571 Kit ($40)
Includes all the parts listed above. There is a choice of knob colours: red + green, yellow + cyan or orange + white (two of each colour).
A kit is also available for the Display Adaptor; see its parts list on page 45 for details (Cat SC6572, $50 + postage).

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Display Adaptor for the BREADBOARD PSU

The Dual Channel Breadboard PSU is compact and handy for prototyping. It slots straight into a breadboard's power rails and can run from a plugpack or USB supply. The Display Adaptor attaches to the Breadboard PSU and displays lots of handy data, such as the set and actual voltages and currents. It even has extra voltmeter and ammeter channels to help you analyse your prototype!

The Breadboard PSU is a compact unit that plugs into a breadboard, providing two voltage adjustable current-limited supply rails. It's a handy tool for prototyping and testing, but by itself, you won't know what voltages you've set or how much current is being drawn.

This add-on module solves that by providing readouts of the setpoint and actual voltage and current for each channel. Since it uses a microcontroller with many analog inputs, we have added extra voltage and current monitoring channels that give you a lot of flexibility.

We've also included a pair of bicolour LEDs to provide status indications and a piezo buzzer to sound alerts. It even calculates an estimate of the dissipation that's occurring in the transistors in the Breadboard PSU, so you can avoid burning them out.

The PSU Display Adaptor simply mounts directly above the Breadboard PSU and doesn't take up any extra bench space.

Display Adaptor

When we designed the Breadboard PSU, we realised it would be pretty easy to add extra circuitry to monitor its operation. This is part of the reason for the numerous headers on the Breadboard PSU. Voltages are applied to pins on those headers that are proportional to voltages and currents in the circuit, making it easy for an add-on board to monitor the status.

Fig.3 shows the circuit of the Display Adaptor. It won't do much without the Breadboard PSU, so the components have been numbered to follow on from that circuit, except for CON5-CON9, which form the inter-board connections and are effectively common to both boards.

We'll also refer to parts on the Breadboard PSU, so you might need to refer to that circuit (Fig.1 on page 32).

Power for the Display Adaptor comes in via CON7, which has connections to ground, the 15V rail and the 5V rail from the PSU. It effectively combines the inputs from CON1 and CON2 on that board.

The Display Adaptor only needs a 5V rail to operate, so REG2 is a 7805 linear 5V regulator accompanied by 100µF input and output capacitors. This larger TO-220 type regulator has been mainly chosen to provide the higher current needed to drive the LED display backlight.

Jumper JP3 allows sourcing power from REG2 or the USB connection if preferred, but we recommend that this jumper be set to the REG position. That's because the regulator's output

Features & Specifications

- Uses a common 20x4 character backlit LCD
- Shows 11 statistics
- Four independent voltages and two currents displayed
- 100mV resolution on voltages, 10mA resolution on currents
- Typically 1% accurate, can be calibrated
- Includes indicator LEDs and over-current warning buzzer
- Shows dissipation estimate for PSU transistors
- Stacks on top of Breadboard PSU for minimal clutter

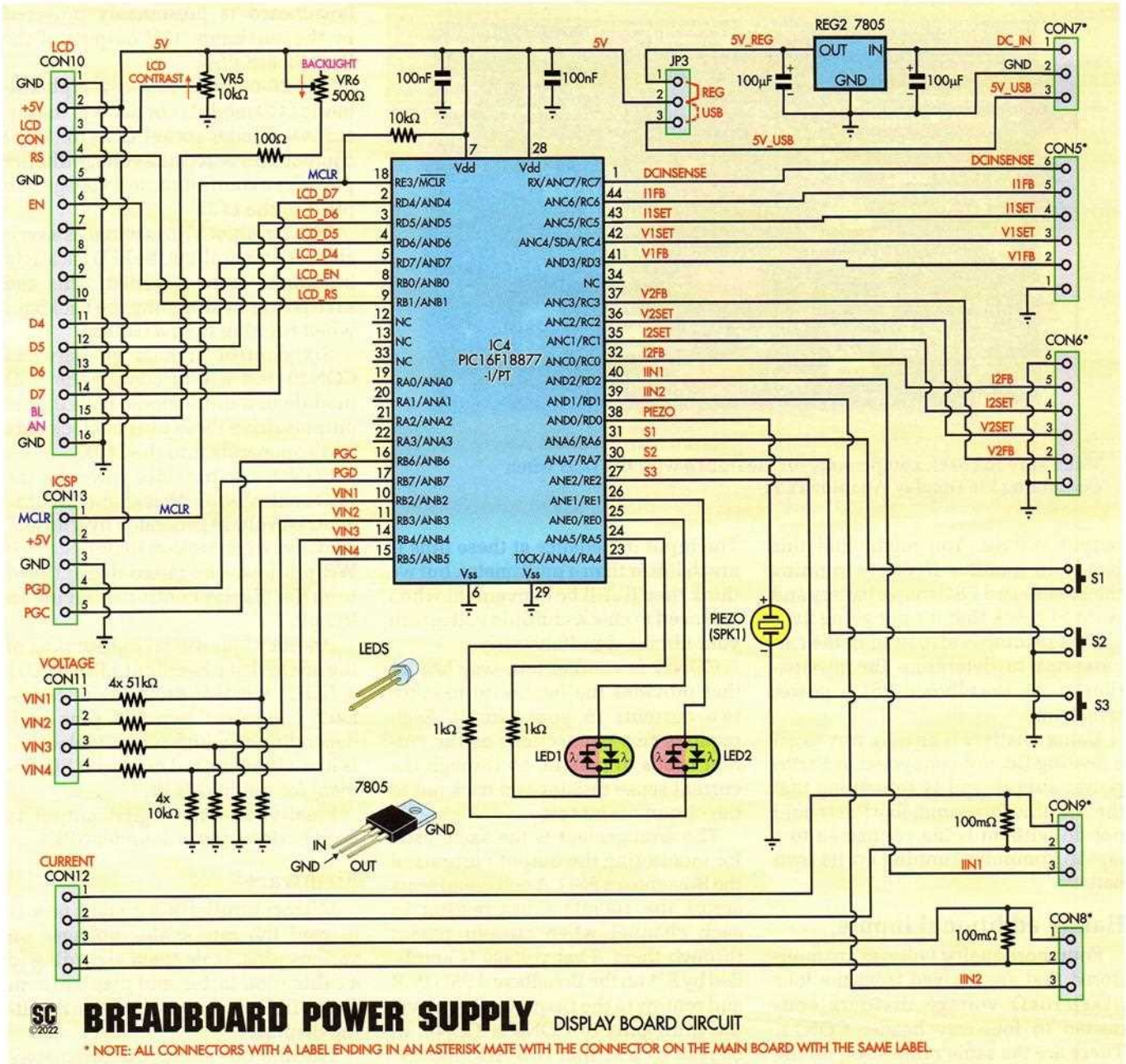


Fig.3: this circuit interfaces with that of the Breadboard PSU (Fig.1 on page 32) via CON5-CON9. CON7 provides power to the Display Adaptor, while CON5 and CON6 supply the voltages measured by the microcontroller IC4. CON8 and CON9 feed the two extra currents that can be measured between the two PCBs.

will be much more accurate and consistent than a USB supply.

IC4 is a 44-pin PIC16F18877 microcontroller, chosen for its numerous input/output (I/O) pins. It's effectively the same part used in the USB Cable Tester from November & December 2021 (siliconchip.au/Series/374), but in a compact TQFP package, which saves a lot of space.

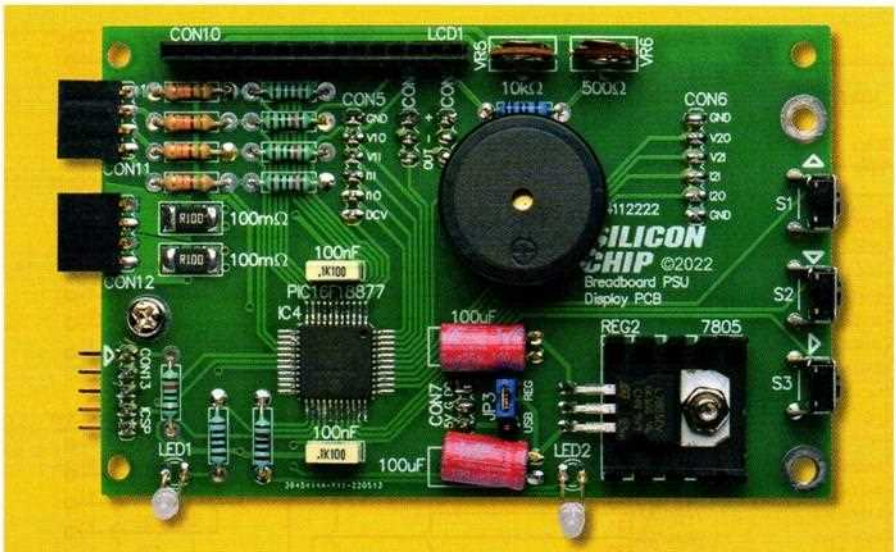
IC4 has two 5V and two ground connections, each pair bypassed by a 100nF capacitor. The in-circuit serial programming (ICSP) pins are taken to CON13 for programming and debugging the microcontroller. If you have a pre-programmed microcontroller, CON13 does not need to be fitted. There is also a 10kΩ pullup resistor on IC4's $\overline{\text{MCLR}}$ pin to prevent spurious resets.

One of the great things about the PIC16F18877 is that its ports and pins are highly interchangeable. While it might look like a complicated chip with many pins, most PCB traces simply fan out in the required direction to the nearest connection point.

Practically all I/O pins are internally connected to the microcontroller's ADC (analog-to-digital converter) peripheral, so we can use them to read and monitor external voltages.

Nine such voltages come from the Breadboard PSU through CON5 and CON6. Eight of these correspond to the actual and setpoint (target) voltages for the current and voltage of each of the two PSU channels.

The remaining voltage to monitor is a divided version of the so-called 15V rail, allowing it to be measured too. This is handy to know as it is the DC supply for the PSU outputs and will dictate such things as the maximum



Make sure to check components for clearance with the LCD when assembling the Display Adaptor PCB.

output voltage. You might find this handy to monitor if you're running the Breadboard PSU from a battery and want to check that it's not going flat.

This reading is also used in the calculations to determine the dissipation in the Breadboard PSU's power transistors.

Using a battery is an easy way to get a floating (ie, not connected to Earth) power supply and is something that the Arduino Programmable PSU could not do without being connected to a laptop computer running on its own battery.

Handy additional inputs

Four more analog voltages are monitored that are derived from the four 51kΩ/10kΩ voltage dividers connected to four-way header CON11. These are the same ratios used on the Breadboard PSU, giving the same nominal 30.5V scale against a 5V reference. You can use these four independent voltage channels to check and monitor your breadboard prototype.

Using the same divider ratios mean that a single (nominal) calibration factor can be used for all voltage inputs. The input impedance at these pins is much lower than a multimeter, but we think they'll still be convenient when you need to check multiple voltages in your circuit simultaneously.

CON12 is another four-way header that provides the facility to monitor two currents in your circuit. Each requires two connections as the current needs to pass in, go through the current sense resistor and back out to the circuit under test.

The arrangement is the same used for monitoring the output currents of the Breadboard PSU. A voltage appears across the 100mΩ shunt resistor in each channel when current passes through them. That voltage is amplified by IC1 on the Breadboard PSU PCB and returns to the Display Adaptor via the third pins of CON8 & CON9, to be read by a further two ADC inputs.

We can do this because IC1 is a quad-channel device and only two of its channels are used by the Breadboard PSU hardware.

The voltages on the current monitor inputs must be no higher than the INA4180's 26V limit. That seems unlikely, given that the circuit on the breadboard is presumably powered by the maximum 15V outputs of the Breadboard PSU.

The 20-column, four-row alphanumeric LCD module connects to the circuit via header socket CON10. 10kΩ trimpot VR5 wired as a voltage divider provides a contrast control voltage into pin 3 of the LCD.

500Ω trimpot VR6 is wired as a variable resistor to allow the LED backlight brightness to be adjusted. This can save power by dimming the backlight when running from a battery.

Six control signals go between CON10 and IC4 to control the LCD module in four-bit mode. IC4's digital outputs drive these pins to clock data and commands into the LCD.

CON10 also provides power for the LCD controller and backlight LED, the contrast voltage generated by VR5 and provides a connection to pull the RD/$\overline{WR}$ pin low. The micro doesn't read from the display controller, saving an I/O pin.

Another four digital output pins of the micro drive bi-colour LEDs (LED1 & LED2) via 1kΩ dropping resistors. Each LED uses two I/O pins and, depending on which is high and which is low, either the red or green LED element (or neither) is lit.

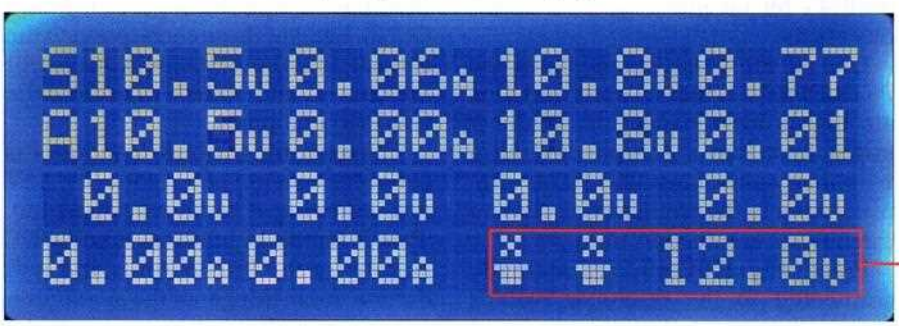
Finally, another digital output is used to drive piezo sounder SPK1.

Firmware

Microcontroller IC4's main task is to read the raw analog voltages on various pins, scale them according to a calibration factor, and display them on the LCD. Screen 1 shows the resulting display.

The first line shows the parameters set by the potentiometers on the Breadboard PSU, indicated by an "S". These are the CON3 voltage (as set by VR1), CON3 current (VR3), CON4 voltage (VR2) and CON4 current (VR4) targets.

As the current-limiting circuitry on the Breadboard PSU pulls down the reference voltages using Q2 and Q4,



Screen 1: everything you need to know is on this screen. To fit everything in, it cycles through the incoming supply voltage and transistor dissipations in the bottom-right corner, as shown in the inset.

the displayed voltage can dip slightly (up to around 0.2V) during current limiting.

The value of the 100kΩ resistors connected to the wipers of VR1 and VR2 is a compromise between this side-effect and providing a low impedance path for the control voltage. So take care not to set these voltages while current limiting is active.

Note that the "A" (for amps) at the end of the first line is implied due to the space needed for the "S" at the start. We've also used custom narrow characters for the units to provide visual separation. These characters use the display's character generator RAM feature.

The second line shows the corresponding measured values, marked by the leading "A" for "actual". For the most part, the voltages should match the setpoints except when the current limit is active, in which case the current should match its setpoint.

The third line shows the 'bonus' voltage readings from CON11, while the first two readings on the fourth line are the currents measured at CON12.

The small icons that follow indicate whether audible alarms are active for the CON3 and CON4 outputs, respectively.

The remaining three statistics share the last five character slots in the lower-right corner of the screen. The dissipation in each main regulator transistor is calculated as the CON3 or CON4 output voltage subtracted from 15V rail voltage, multiplied by the appropriate current.

The display cycles every two seconds between showing the 15V rail voltage (which won't necessarily be 15V) and the two calculated dissipation figures of Q1 and Q3 on the Breadboard PSU.

This is possible because the dissipation is expected to be in the range of single digit (0-9) watts, so it can be displayed very compactly. You can see this in the Screen 1 inset. If the reading is above 9W, it is clamped to 9W for simplicity.

Besides driving the display, which takes up most of the microcontroller's time, it also monitors pushbutton switches S1-S3 and lights up LED1 and LED2 depending on the prevailing conditions.

The purpose of those switches and LEDs will be described later, in the section on using this unit. In brief, the buttons allow the audible alarm for either channel to be toggled and all the values displayed to be calibrated. The LEDs indicate when either channel is in current limiting or otherwise unable to achieve the desired voltage.

Construction

Start by fitting out the PCB for the Display Adaptor, which measures 99 × 63mm and is coded 04112222, referring to overlay diagram Fig.4.

There are five surface-mounting parts, but none are that difficult to handle. You should have flux and solder wicking braid at the very least, as the pins on IC4 are fairly close together. Flux will help the solder flow in the right places, and the braid will help remove it if it gets where it shouldn't.

We also recommend having tweezers, a fine-tipped soldering iron, good illumination and a magnifier to help you check your soldering.

Start by soldering the microcontroller, IC4. Lay down some flux on the pads and align it on all four sides. The TQFP part is a bit more fiddly than, say, an SOIC part that only has pins along two sides.

Roughly place it and check that the pin 1 dot matches the PCB silkscreen. Tack one pin in place and check that it is flat and that all the pins are above the correct pads. If not, apply heat to the soldered pins and gently adjust the chip's position with tweezers until all the pins are perfectly aligned.

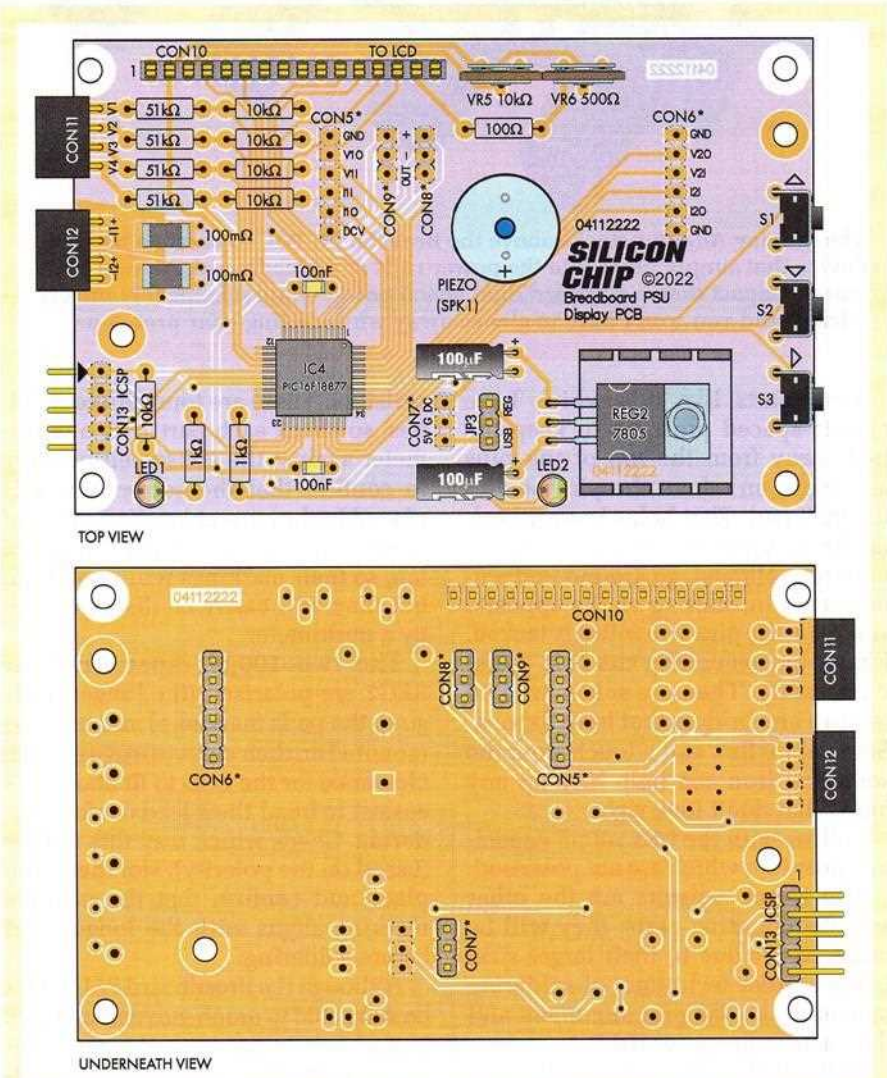
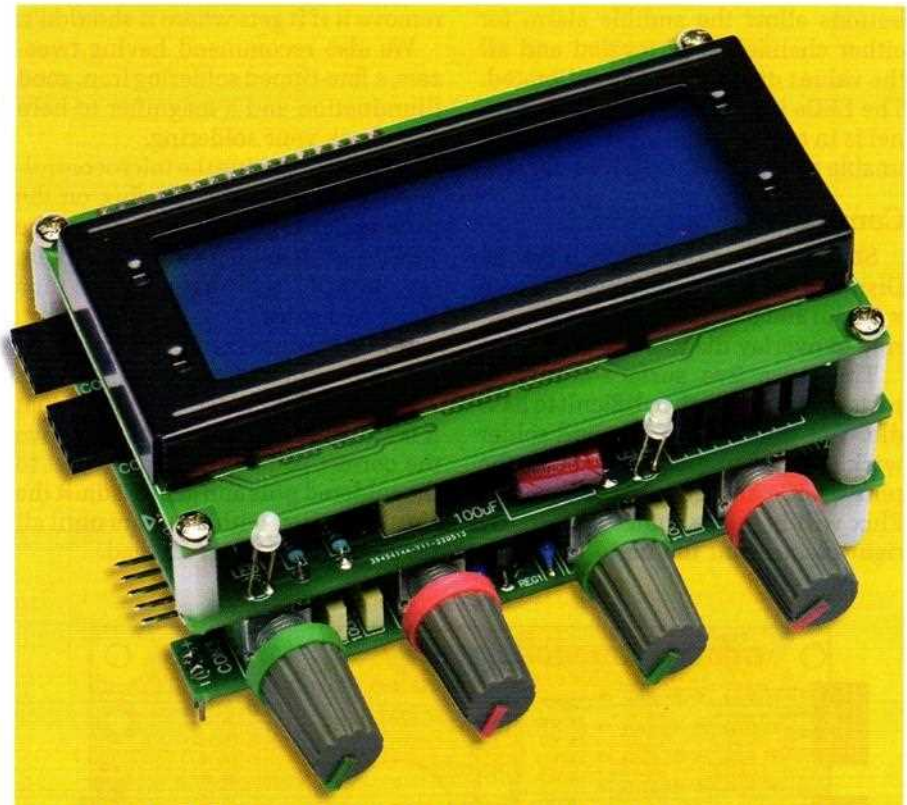


Fig.4: the Display Adaptor is much the same size as the LCD module that sits above it. Pin headers CON5-CON9 are fitted below this PCB to connect to the Breadboard PSU. We also recommend that the ICSP header (if fitted) go underneath the PCB to give clearance for the LCD. The LEDs are installed last to align with the top of the LCD, while the trimpots and piezo should be checked for clearance below the LCD.



The Display Adaptor stacks above the Breadboard PSU to create a handy device that simply plugs into the power rails of a breadboard. It's much more compact than a standard dual bench power supply, helps tidy unruly wiring, and you won't have to glance away while testing your prototype.

With parts like this which have closely-spaced pins, try to keep the iron away from the top of the pins and work on where the pin touches the PCB pad. That helps to avoid solder bridges forming between the pins.

With it aligned, go around and solder each pin, starting on the opposite side from the pins you initially tacked. Finish by retouching the first pin(s) if necessary. Then use solder wick to remove any bridges that have formed. Some more flux and a touch from the soldering iron can help tidy up any joints that don't look right.

Follow with the two 100nF capacitors near IC4, which are not polarised.

The shunt resistors are the other surface-mounting parts; they will be much easier due to their larger size. Use a similar technique of soldering one lead, checking for alignment and then solder the other side.

With all the SMDs fitted, clean off any flux residue using a flux remover or alcohol (eg, isopropyl or methylated spirits) and a lint-free cloth and/or Nylon brush. Allow it to dry fully before proceeding.

You can then fit the through-hole resistors. There are four different values, so check each part with a multimeter against the silkscreen printing to confirm that the correct value is placed in the correct location. Most of them have values that are powers of ten, so their markings will be similar, but they will easily be distinguished by a multimeter.

The two 100µF capacitors near REG2 are polarised (the longer leads go to the pads marked +) and must be mounted on their sides to leave enough clearance for the LCD to fit above. It's easiest to bend their leads before soldering. Check which way this will be (based on the polarity), slot them into place and confirm that the positive marking aligns with the longer lead before soldering.

Although the Breadboard PSU won't be subjected to much movement, there is no harm in securing the capacitor bodies to the PCB with a dab of neutral-cure silicone sealant.

REG2 is fitted similarly to the transistors on the Breadboard PSU PCB. Bend the leads back 90° around 7mm from the body of the regulator, slot them into the holes in the PCB and then slip the heatsink underneath. Thread the machine screw through from below and loosely secure it with the washer and nut.

Adjust the regulator and heatsink to be square and within the silkscreen markings, then nip up the nut, being careful not to twist the regulator. The leads can then be soldered and trimmed.

Solder the three-way header for JP3 now, then fit the jumper to the REG position (across the top two pins), unless you have configured the Breadboard PSU to use USB power.

Right-angle switches S1-S3 will only fit one way, with their buttons facing out from the PCB. Just check that they are lined up neatly before soldering.

CON11, CON12 and CON13 (if needed) can be soldered next. We used right-angle female headers for CON11 and CON12 as these will accept jumper wires for prototyping. If you can't get right-angle types (they will be included in our kit), you can carefully bend the pins of vertical types before soldering.

We installed CON13 underneath the Display Adaptor PCB as this gave the best clearance to the adjacent spacer for connecting a programmer. Check our photos for how CON11, CON12 and CON13 look on our prototype.

Final assembly

Remove the screws and tapped spacers from the Breadboard PSU, then fit the tapped spacers to the LCD module, so that we can use it to align and check the next steps of the assembly.

Orientate the LCD module so that the 16-way header is at upper left with the display upward. If there are text labels for the pins, these should be the right way up. This is the normal orientation of the LCD module as we describe the assembly in the following.

The tapped spacers along the left (top and bottom) and top right of the LCD module should be secured with the short (5-6mm) machine screws. The spacer at lower right uses the 32-35mm machine screw as this forms the top of a stack of three spacers.

Mount the trimpots similarly to the switches. They will need to be pushed down firmly against the PCB to ensure they do not foul the LCD module above. You can check this by temporarily slotting the LCD module

above, using the longer machine screw for alignment.

Then fit the piezo buzzer, making sure to check the polarity markings. Some of these devices are pretty tall; check the clearance there too.

If you haven't yet fitted the 16-way header to the LCD module, do this now. You can then use it to square up the 16-way female header attached to the Display Adaptor PCB that connects to the LCD module. Solder the female header to the Display Adaptor PCB, then separate the two boards.

Temporarily fit three tapped spacers above the Breadboard PSU PCB, with short screws coming up from below. This will allow you to align the headers from Display Adaptor PCB.

If you haven't fitted CON5-CON9 to the Breadboard PSU PCB, do that first. Then slot the corresponding headers into the top of them, rest the Display Adaptor PCB over them, and solder them while everything is aligned.

Separate the two PCBs and remove the temporary spacers from the Breadboard PSU PCB.

The final components to be soldered to the Display Adaptor PCB are the two LEDs; they are positioned to poke over the top of the LCD module's PCB, making them just visible below the display. So we will fit them after the LCD module is fitted to the Display Adaptor PCB.

The Display Adaptor PCB should have six unoccupied M3 mounting holes at this stage. The four in the corners are for the LCD above, so leave them free.

Fit the other two 'spare' mounting holes with tapped spacers. Put a tapped spacer below the one on the left (between CON12 and CON13) and secure it with a short machine screw from above. The hole at upper right (next to S1) should be fitted with the 20-25mm machine screw and secured with a tapped spacer below.

Fit the LCD module to the Display Adaptor and secure it with three short machine screws into the tapped spacers with short screws at their other ends. The bottom right corner can have another tapped spacer threaded over the 32-35mm screw that is already fitted.

Orientate the LEDs so that they light up red when the left-most lead is more positive than the right. You can use a multimeter on diode test mode to check that, then solder the LEDs so they protrude just above the LCD module.

Now add the Breadboard PSU PCB to the bottom of the stack. Check for clearances and trim any leads that might foul components below. If things are still very close, you can add some insulating material between the two.

Secure the Breadboard PSU PCB at its left-hand (breadboard) end by a machine screw into the underside of the tapped spacer. The last two tapped spacers cover the two exposed screw threads on the right to form the feet, similarly to the bare Breadboard PSU. This secures the other end of the PCB stack and completes the assembly.

Powering it up

If you wish to tread cautiously when applying power for the first time, use a current-limited PSU set to around 100mA or a 9V battery. Make sure there isn't anything connected to CON3 or CON4.

The LCD backlight should light up, but you might need to adjust the contrast trimpot VR5 to get a legible display. After that, it should look much like Screen 1, although the displayed values will probably differ.

Check that the voltage at bottom right is about half a volt below the supply at CON1. With nothing connected, it should cycle between the input voltage and "0W 0W".

Pressing S1 or S2 should toggle the alert icons at lower right. If one of the LEDs is red, the piezo should sound when its alarm is unmuted. If this isn't the case, the LEDs may be reversed.

To check this, dial up the current limit to about halfway; you should get a reading of about 1.25A on the top line. Set the voltages to their minimums. This results in a state where the LEDs should definitely be green.

The easiest way to force a red LED alarm state is to dial the voltage potentiometers to their maximum and the current limits to their minimum. This should also result in an audible alarm from the piezo if the alarm is unmuted.

Parts List – Breadboard PSU Display Adaptor

1 double-sided PCB coded 04112222, measuring 99mm x 63mm
1 20×4 alphanumeric LCD with backlight (LCD1)
1 self-oscillating piezo transducer (SPK1)
1 10kΩ side-adjust trimpot (VR5) **[Jaycar RT4016]**
1 500Ω side-adjust trimpot (VR6) **[Jaycar RT4008]**
3 right-angle SPST tactile pushbutton (S1-S3)
2 6-way pin headers (CON5, CON6)
4 3-way pin headers (CON7-CON9, JP3)
1 jumper shunt (JP3)
1 16-way female header (CON10; for LCD1)
1 16-way header (for LCD1)
2 4-way right-angle female headers (CON11, CON12)
1 5-way right-angle pin header (CON13; **optional**, for ICSP)
1 small TO-220 finned flag heatsink
7 12mm-long M3 tapped spacers
1 M3 × 32-35mm panhead machine screw **[Jaycar HP0418]**
1 M3 × 20-25mm panhead machine screw **[Jaycar HP0414]**
7 M3 × 5-6mm panhead machine screws
1 M3 shakeproof washer
1 M3 hex nut

SC6572 Kit ($50)
Includes all the parts listed.

Semiconductors
1 PIC16F18877-I/PT 8-bit microcontroller programmed with 0411222A.HEX, TQFP-44 (IC4)
1 7805 5V 1A linear regulator, TO-220 (REG2)
2 bi-colour red/green 3mm LEDs (LED1, LED2) **[Jaycar ZD0248]**

Capacitors
2 100µF 25V radial electrolytic
2 100nF 25V M3216/1206 X5R/X7R ceramic, radial ceramic or MKT

Resistors *(all ¼W 1% axial except as noted)*
4 51kΩ 5 10kΩ 2 1kΩ 1 100Ω
2 100mΩ M6432/2512 1W SMD

Finally, you can check that S3 cycles through the various calibration screens. If that's the case, then the Display Adaptor is working as expected. If the LEDs show the wrong colour, desolder them and swap their leads.

Calibration

In regular use, a single screen displays all applicable information, previously shown in Screen 1. This is shown at power-up, so you can use the Display Adaptor without pressing any buttons.

If the readouts you see on the Display Adaptor are off by more than 5%, we recommend checking your construction, as it should be closer than that without calibration. Start by checking all the divider resistors.

The 1% tolerance components specified will be more than adequate for most purposes and within the resolution of the displayed values, so calibration is optional.

Pressing S3 accesses the calibration factors for all the displayed parameters, except the transistor dissipations, which are set by their constituent voltages and currents. Each press of S3 simply cycles through each in turn until you return to Screen 1.

Screen 2 shows a typical calibration page. The calibration factors are displayed in the same order as on the main screen, but the second line of text also describes the parameter.

The third line shows the calculated value of that parameter using the current calibration factor, which is seen on the line below. The calibration factor is changed using S1 and S2 to adjust up and down.

Thus, the simplest way to calibrate is to use a multimeter to measure the parameter (voltage or current) and then adjust the calibration factor until they agree.

Because all voltages use the same 51kΩ/10kΩ divider, their default calibration factors are the same. Similarly, all currents have a different corresponding calibration factor.

Use a multimeter to read the voltage or current you wish to calibrate. Note that for currents, you will need to apply some sort of load and make sure that current limiting is active to check the setpoints.

Select the appropriate screen, then adjust the calibration factor up or down using S1 and S2, respectively, until the multimeter reading matches the displayed reading.

Take care that you have the correct screen, as there are quite a few different parameters. After that, return to the main screen and check that the displayed values are consistent.

The final calibration page (Screen 3) allows the calibration factors to be saved to EEPROM, meaning they will be stored permanently for future use. Simply press S1 and S2 together on this page to permanently save the data. A message will be displayed to confirm this has happened.

Screen 2: all the main parameters shown on the main screen can be calibrated using these screens. Simply read off the actual voltage with a multimeter and use S1 and S2 to adjust the displayed voltage until it matches.

Screen3: the calibration factors can be saved to non-volatile EEPROM by pressing S1 and S2 simultaneously on this page.

Using it

From now, the Display Adaptor simply displays the various voltages and currents set and used by the Breadboard PSU. You can mute and unmute the alarms with S1 and S2.

The power display at lower right that alternates with the supply voltage will warn of conditions that might overheat the Breadboard PSU's transistors. The display reads 0W-9W for each channel, as that's all it can show in the available space. The design is intended to handle up to 3W continuously and up to 5W for short periods.

If you see these creeping up any higher, shut down the circuit to avoid damage to the Breadboard PSU.

With everything set up, you shouldn't need to do anything with the Display Adaptor except read what it displays.

On the main screen, S1 and S2 toggle the audible alarms for the CON3 and CON4 outputs, respectively. A speaker icon with an "x" indicates that the alarm is muted, which is the power-up default.

Since LED1 sits above VR1 and LED2 sits above VR2, each LED corresponds to one channel of the Breadboard PSU. Usually, the green LED is lit for each channel. If IC4 detects that the actual voltage is not near the setpoint voltage, it changes the LED to red. In practice, this means that the current limiting has activated, although it can also happen if the voltage potentiometers are set above the DC input voltage.

If the alarm for the corresponding channel is not muted, the piezo sounds in short chirps when the corresponding LED is red. That should get your attention without being as annoying as if it sounded constantly.

While the Breadboard PSU lacks an on/off or load disconnect switch, it's quite easy to pull out the side plugged into the breadboard, which disconnects it. It would be a good idea to do that immediately, if you notice the transistor dissipation values are unexpectedly high or something else is wrong. SC

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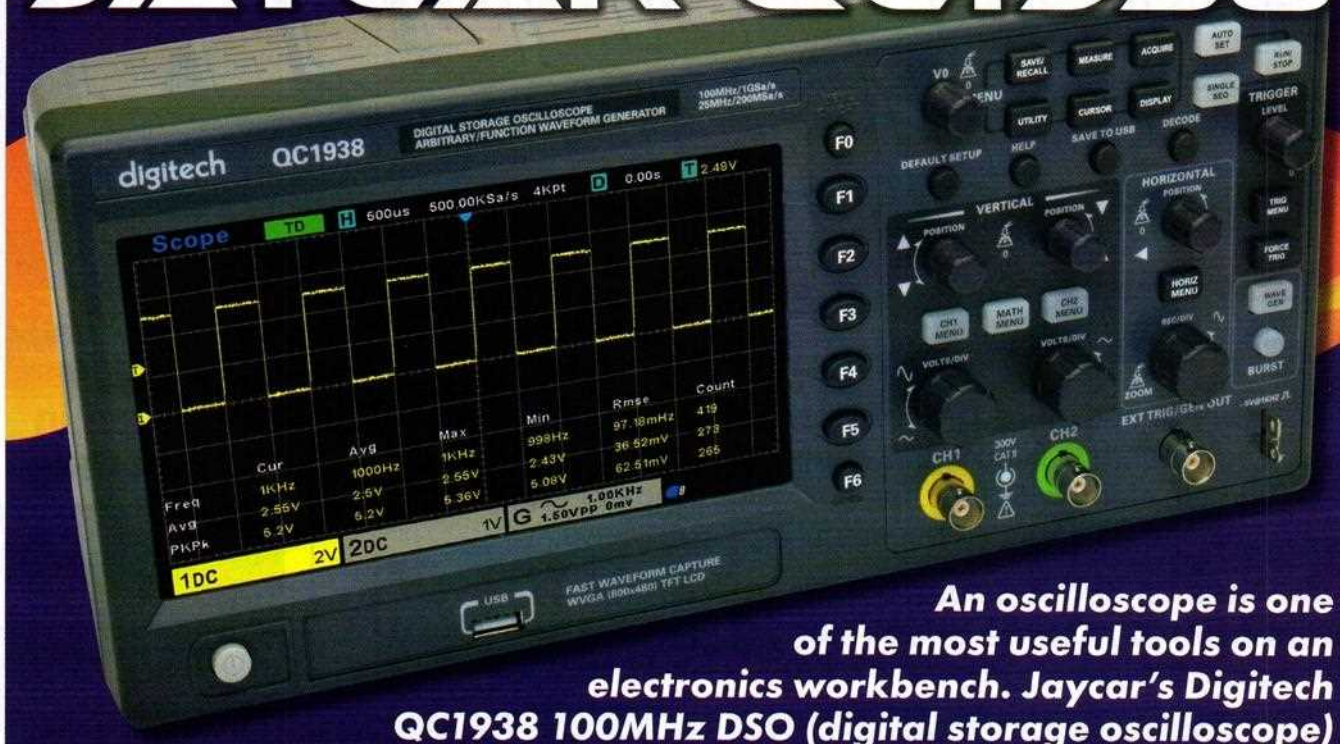
DUAL-CHANNEL OSCILLOSCOPE
JAYCAR QC1938



An oscilloscope is one of the most useful tools on an electronics workbench. Jaycar's Digitech QC1938 100MHz DSO (digital storage oscilloscope) was released a few months ago, and they sent us a unit to try out.

Jaycar has recently started selling the QC1938 two-channel, 100MHz DSO with a 1GSa/s sampling rate and 8MSa (megasample) storage. Having digital storage brings many advantages that we will describe shortly.

Some of its more noteworthy features include a dual display (zoom) mode, numerous serial protocol decoders and an arbitrary waveform generator. The display is a 7in (18cm) diagonal TFT LCD with a resolution of 800 × 480 pixels. It does not have a touchscreen interface.

Our loaned review unit came in standard retail packaging, so our experience is the same as if we had bought it. It comes with a single 10:1 probe, a pair of BNC-alligator leads, an IEC power cable, a USB cable and a software CD. The software is also downloadable from the Jaycar website product page for those without an optical drive.

The unit comes well-packed and is relatively compact at 32cm wide, 15cm tall and 11cm deep. The power cable plugs into a recessed receptacle on the left side, meaning you can push it back against a wall.

The QC1938 feels sturdy. The numerous controls mean it could not be much smaller, except perhaps by being slightly less deep. A folding handle is recessed into the top, and it has ample vent holes.

It would definitely be nice to have a second probe included, given that this is a dual-channel oscilloscope. Still, the BNC-alligator leads are usable for modest frequencies (eg, audio or low-speed digital signals), but definitely not up to the full 100MHz. You can purchase a second probe from Jaycar (Cat QC1902) for $39.95, rated at 60MHz on the 10:1 setting or 6MHz on the 1:1 setting.

Documentation

We had a good read through the user manual to get an idea of what to expect. There are numerous features listed that we thought sounded handy. We do a lot of digital or mixed digital/analog designs, so serial protocol decoding is one feature we'd use a lot.

Review by Tim Blythman

The protocols include UART, LIN, CAN, I²C and SPI, which covers most of the protocols that we use. As we noted in our review of PicoScope 6426E (October 2021; siliconchip.au/Article/15068), having an ample sampling depth makes it easier to decode longer communication sequences.

Like many modern digital oscilloscopes, the QC1938 has a USB port; two, in fact. A USB-B socket at the back allows the oscilloscope to be connected to a host PC. We'll investigate this feature and the accompanying software later.

A USB-A socket on the front allows a USB drive to be connected. You can use this to save screenshots and perform firmware updates. It turns out that the QC1938 is actually a small Linux computer equipped with custom hardware allowing it to act as an oscilloscope.

The waveform generator can deliver sine and square waves, noise, or even an arbitrary waveform of up to 4096

The screen is large and bright, so much so that we had no trouble viewing it outdoors. Adjacent to the screen are the basic oscilloscope controls, while the other features are accessed from a variety of buttons along the top and side of the front panel.

All the included accessories are shown here. While the alligator clip leads limit the usable frequency, they are sometimes easier to connect to circuit points than a proper probe.

samples. The waveform can also be amplitude- or frequency-modulated (AM/FM).

Another features that we think will be quite handy is the dual window (zoom) view, which shows the entire waveform on the top half of the screen and a zoomed subsample in the lower half.

The waveform output socket is also labelled as the external trigger. This shouldn't be a problem as long as you remember whether this socket is an input (external trigger) or output (waveform generator) at any given time. Still, it would be nice to have two separate connectors.

The QC1938 has foldable feet so that the oscilloscope can be tilted up slightly and gives a much better view of the screen and access to the controls than it would on a flat bench. The rear feet are rubberised and are sufficient to keep it from sliding around.

There is also a DEFAULT SETUP button that reverts the oscilloscope to its default settings, in case you have gotten it into a state where you can't figure out how to change it back.

Hands-on testing

After spending a bit of time getting accustomed to the various controls, we found that the QC1938 is very easy and intuitive to use.

There is a delay of about 10 seconds after powering it on before it is ready, which seems reasonable. For example, the more expensive Rigol MSO5354 mixed signal oscilloscope takes up to a minute. We reviewed that unit in the February 2019 issue (siliconchip.au/Article/11404).

A self-calibration routine is available via the UTILITY menu. When we first ran this, it appeared to need a few cycles before settling and completing calibration; subsequent calibrations took about two minutes. It's recommended that this is done after the oscilloscope has warmed up and stabilised.

The controls, visible in the front photo, have a variety of functions, but all work in a uniform fashion. Pressing one of the buttons shows a list of soft options alongside the F1-F5 buttons on the display.

Items that use the soft menu include MATH, SAVE/RECALL, MEASURE, ACQUIRE, UTILITY, CURSOR, DISPLAY, TRIGGER, DECODE and WAVE GEN. This covers most of the features beyond the basic functions.

Pressing F0 at any time hides the soft menu options, while F6 flips to the second page of options if available. The V0 knob allows numerical soft menu options to be dialled in easily.

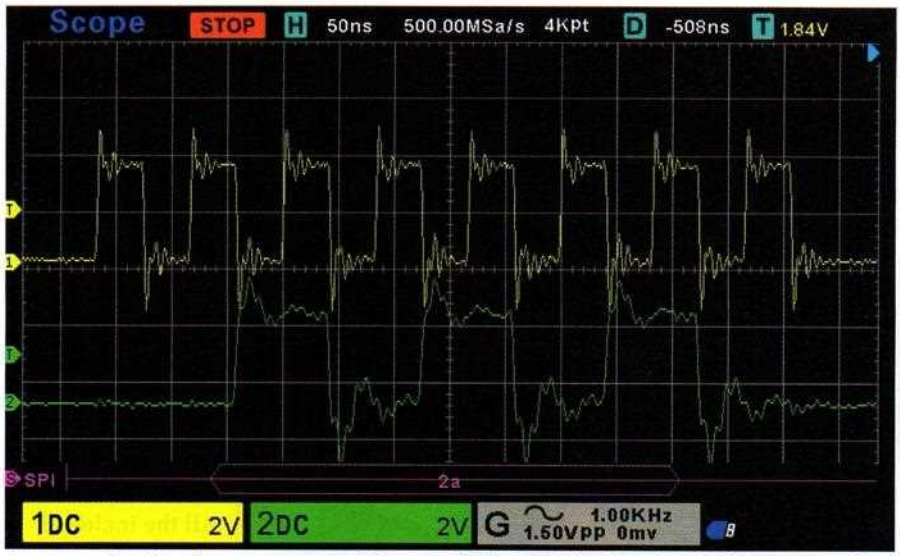
Several of the buttons light up, and where appropriate, they match their colour on the display. For example, the CH1 trace is displayed in yellow and the CH1 menu button is lit up in orange (near enough to yellow) when CH1 is active. CH2 is similarly green.

The MATH-generated trace is purple and is controlled by the MATH MENU button, which lights up purple. MATH functions include FFT (fast Fourier transform spectral analysis), add, subtract, multiply and divide.

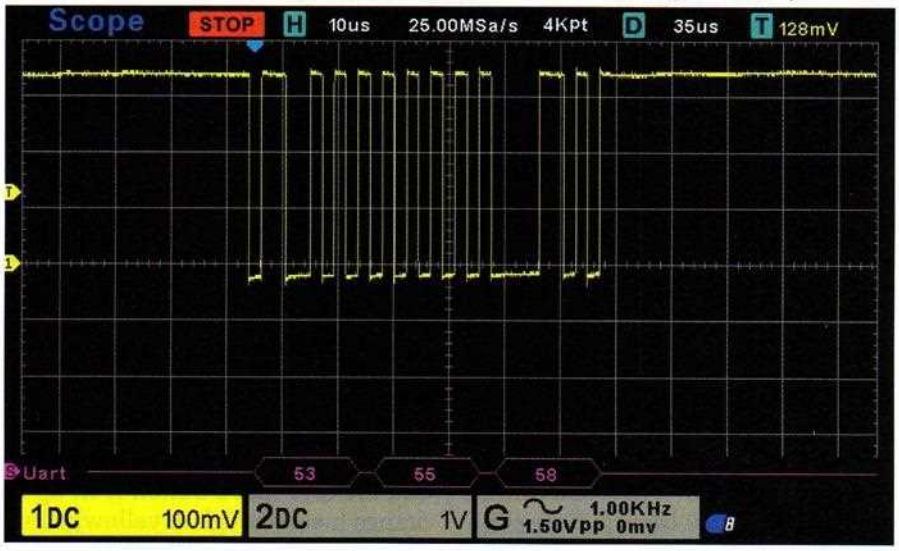
The RUN/STOP button is either red or green to indicate whether continuous triggering is occurring. The WAVE GEN button lights up blue when it is active.

The MEASURE button brings up over 30 parameters, such as frequency, amplitude and duty cycle, measured from the displayed waveform. While you might often be interested in a handful of these, being able to quickly see many different parameters is handy too. A small subset can be chosen to be displayed along the bottom of the oscilloscope display.

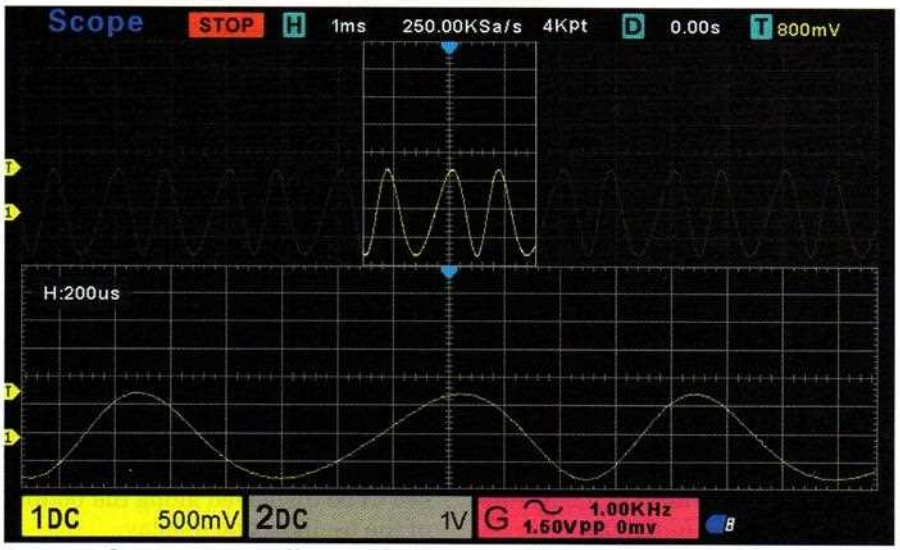
The most difficult part of the learning curve for this oscilloscope is



Scope 1: despite the apparent noisiness of this 12MHz SPI signal, the QC1938 has correctly decoded it. The decoded date is in purple below the green trace, and uses lower case characters for hexadecimal digits. It is odd that the hexagonal 'box' containing the decoded data does not bracket the full eight clock cycles.



Scope 2: this shows the oscilloscope decoding three consecutive serial bytes at 460400 baud, the fastest UART data it can decode. The protocol decoders can also trigger the scope on a data match, a handy way to synchronise it to other events.



Scope 3: the zoom view offers a split screen and is a good way to view a small part of a waveform without twiddling back and forth between time scales.

becoming familiar with the menu locations of all the options, but they are all quite intuitive once you have found them.

Serial protocol decoding

We hooked up the QC1938 to the SPI lines on an LCD BackPack to test the protocol decoding. We used the probe on the clock line for CH1 (since this is the faster signal) and one of the BNC-alligator leads for data on CH2.

Initially, we could not see any decoded data no matter what we tried. We contacted Jaycar, and they determined that this was due to a firmware bug that was fixed in a later version. The oscilloscope we received originally had version 3204 of the firmware (the current version is listed under the UTILITY menu). The update to version 3205 only took a couple of minutes.

Jaycar has told us that this updated firmware file will be available for download on their website. So if you receive a QC1938 oscilloscope with version 3204 of the firmware, you should update it.

After that, we had no trouble getting the protocol decoding working with our SPI data.

By the way, we also experienced a couple of 'freezes' with the older firmware, where the oscilloscope randomly stopped responding to user input. We didn't experience that anymore after the firmware update.

You can see in Scope 1 that the clock line is cleaner than the data line (because we're using the proper probe). The decoded value is shown below. We know this data is correct as the 0x2A (2a) command is regularly used by the BackPack software.

The 12MHz signal shown is as fast as we could successfully decode using the BNC-alligator leads, with faster signals returning corrupted data. So you will need a second probe to work with faster SPI signals.

Note that decoding of SPI data is pretty limited on any two-channel oscilloscope; it would be preferable to have extra channels available for connecting other data channels and slave select lines. If you frequently probe SPI buses, a four-channel oscilloscope or dedicated logic analyser might be a better choice.

Scope 2 shows UART data being decoded at 460400 baud – this is the fastest UART baud rate that the QC1938 can decode. We had no

problems with UART decoding, even after trying several baud rates.

Protocol decoding also requires you to set a matching trigger setting; these seem to duplicate the decoding settings, but mostly need to be changed separately. It is also necessary to set the threshold when multiple channels are involved in the decoding, such as I^2C and SPI.

The oscilloscope has handy features like being able to match on specific data values, including exact matches, mismatches and comparisons. This makes it much easier to sift through large amounts of data.

The sample depth appears to be fixed at 4kSa when decoding is active, so the full 8MSa is not available. We think the protocol decoding would be better if it could use the entire sample memory, as it would allow longer sequences to be decoded.

Zoom view

The zoom feature is a simple and effective way of inspecting a waveform closely. It's activated by pressing down on the timebase knob; there are markings on the oscilloscope controls to this effect.

When zoom is active, the screen is split; the full waveform is shown in the top half, and a zoomed version is below. A window over the full waveform shows the portion shown in the zoomed version. You can see what this looks like in Scope 3.

The timebase and horizontal position controls are then used to change the extent and position of the zoomed window. It all works intuitively, with the lower window showing the zoomed graticule spacing and a time offset.

We thought it was handy to view a longer waveform and also be able to inspect it closely. Our only complaint is that the zoom and time offset settings are reset when you leave the zoomed view.

USB interfaces and software

The included software is called HantekDSO2000; the QC1938 appears very similar to the Hantek model DSO2D10. From what we could see, only Windows software is provided; we tested it on a Windows 11 machine.

The provided software includes a DigitalScope program, which is the virtual oscilloscope program that interfaces to the QC1938 and a WaveEditor program. WaveEditor is used to generate files for the arbitrary waveform generator on the oscilloscope.

The included USB-A to USB-B cable allows a host computer to be connected to the USB-B socket at the rear of the oscilloscope. Oddly, we could not establish communication through any of the USB 3.0 ports on our computer. Interposing a USB 2.0 hub fixed this problem.

The USB port in the back of the oscilloscope is not recessed like the power socket, so using the USB socket will eat into the space on your bench.

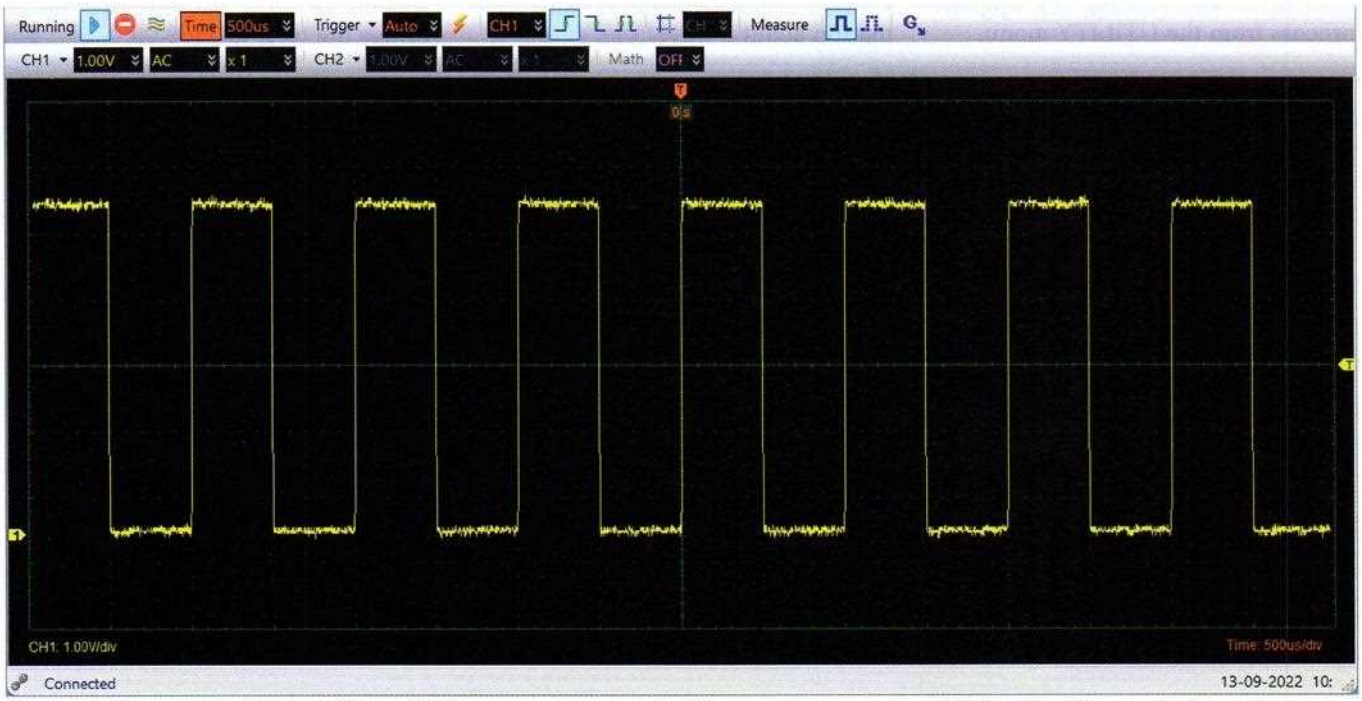
Screen 1 shows the software with an active oscilloscope view. We found that the software mostly echoed the features and controls on the oscilloscope itself. The trace takes up most of the window, with the controls compressed to a small region above.

When the software is controlling the oscilloscope, its controls are disabled, so we mostly preferred to use the oscilloscope in standalone mode without the USB connection to a computer.

Screen 2 shows WaveEditor. It has various settings for generating simple waveforms such as sine, square and triangular waves. Waveforms can also be drawn freehand or imported from and exported to CSV (comma-separated variable) format files, allowing manipulation by spreadsheet programs.

With that said, the inbuilt wave generator can deliver several different waveforms at an adjustable frequency and amplitude and can AM or FM modulate the output to produce complex waveforms without the hassle of delving into WaveEditor.

The USB-A socket on the front of the oscilloscope is for connecting a USB flash drive. You can't use it at the same



Screen 1: the supplied "DigitalScope" PC program can control the oscilloscope via a USB cable. The controls on the oscilloscope are disabled when the USB interface is running, so we didn't use this software much. It might be convenient if you take a lot of screen grabs as they can be stored directly on the host computer.

time as the other USB connection since the controls are disabled.

As you might expect, it can be used for exporting screen grabs. These are transferred as uncompressed 24-bit bitmaps (BMP) files. We prefer PNG files as they are compressed (losslessly) and thus take less time and space to move around, but storage is cheap enough that it is not a big problem.

Saving a screen grab is as simple as pressing the "SAVE TO USB" button on the oscilloscope's front panel. Unfortunately, the oscilloscope does not have a real-time clock, so it can't timestamp the grabs. Instead, the files are stamped based on the time since the oscilloscope was turned on, so you can at least distinguish the order within a given session.

Display configurations (real and calculated trace scales and positions, measured parameters) can also be saved and recalled. There are internal memory slots for this purpose, too, so we would use this feature mainly for different testing schemes.

Waveforms for the arbitrary waveform generator can also be transferred to the oscilloscope as files via a USB flash drive. As noted, these can be created in the WaveEditor program.

And as we found out earlier, firmware upgrades can be applied by copying the necessary upgrade file onto a USB drive and starting the upgrade process from the UTILITY menu.

Like many other oscilloscopes, the most use we made of the USB feature was to create screen grabs by saving them to a USB flash drive, although we occasionally uploaded waveforms from the WaveEditor program.

The display and controls on the oscilloscope itself are pretty good, so we found little use for the host USB interface, especially as the cable sticks out the back and gets in the way.

Our evaluation

The main features of the QC1938 are laid out in a standard manner, so they should be familiar even if you are only familiar with the most basic oscilloscopes.

There are a couple of missing features that would have been nice to have, such as a real-time clock and the ability to export PNG screen grabs. While the former would require a small amount of extra hardware, the latter could possibly occur in the future with a firmware upgrade.

The 100MHz bandwidth is ample for almost anything we do, although you need another oscilloscope probe to use the full bandwidth on both channels.

Some of the values that are dialled in using the V0 knob have a very broad span and can take a while to select. It's a pity that it does not have a fine/coarse adjustment option to speed that up.

The MEASURE and MATH displays are very useful for gleaning extra information about a waveform.

There is some noticeable warmth above the vent at the left-hand end of the case, which is presumably where the power supply is located adjacent to the incoming mains. But we never noticed it getting too hot to touch.

Summary

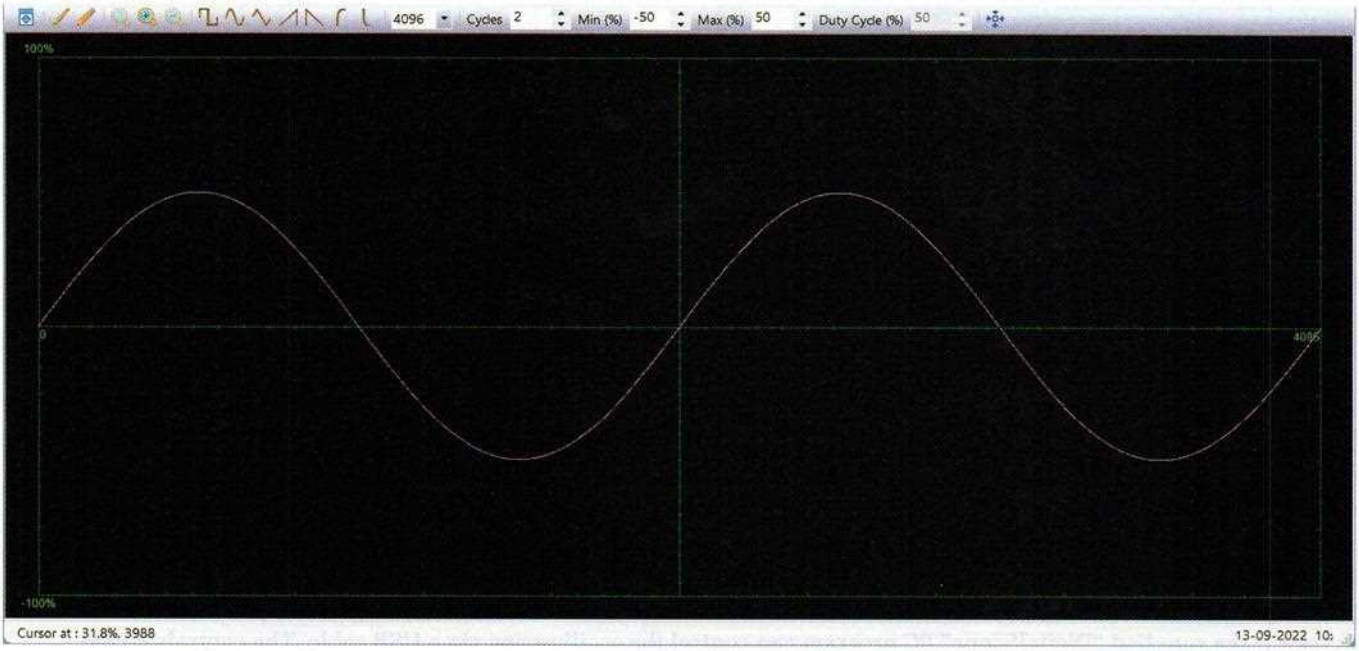
While we have some minor feature requests that we've seen before on other similar oscilloscopes, overall, the QC1938 is an oscilloscope that is easy to use and will do practically everything the average user needs.

The 100MHz bandwidth is fairly standard and covers many use cases, although we definitely recommend purchasing a second proper oscilloscope probe. We also recommend performing the firmware update straight away if your oscilloscope is on firmware version 3204 or earlier.

This is certainly a good choice of oscilloscope for reasonably advanced users but also for anyone getting started with oscilloscopes; it has the features to make it useful for years to come.

The standard inclusion of serial protocol decoders, a waveform generator, a decent memory depth and zoom feature makes it good value at the price.

The QC1938 DSO is available from Jaycar stores and online (www.jaycar.com.au/p/QC1938) for $549, including GST, at the time of writing. Adding the second QC1902 oscilloscope probe brings the total to $588.95. SC



Screen 2: "WaveEditor" makes it very easy to create all sorts of arbitrary waveforms. They can be saved as files to be copied over to the oscilloscope. As well as some basic presets, waveforms can be drawn or imported from CSV files.

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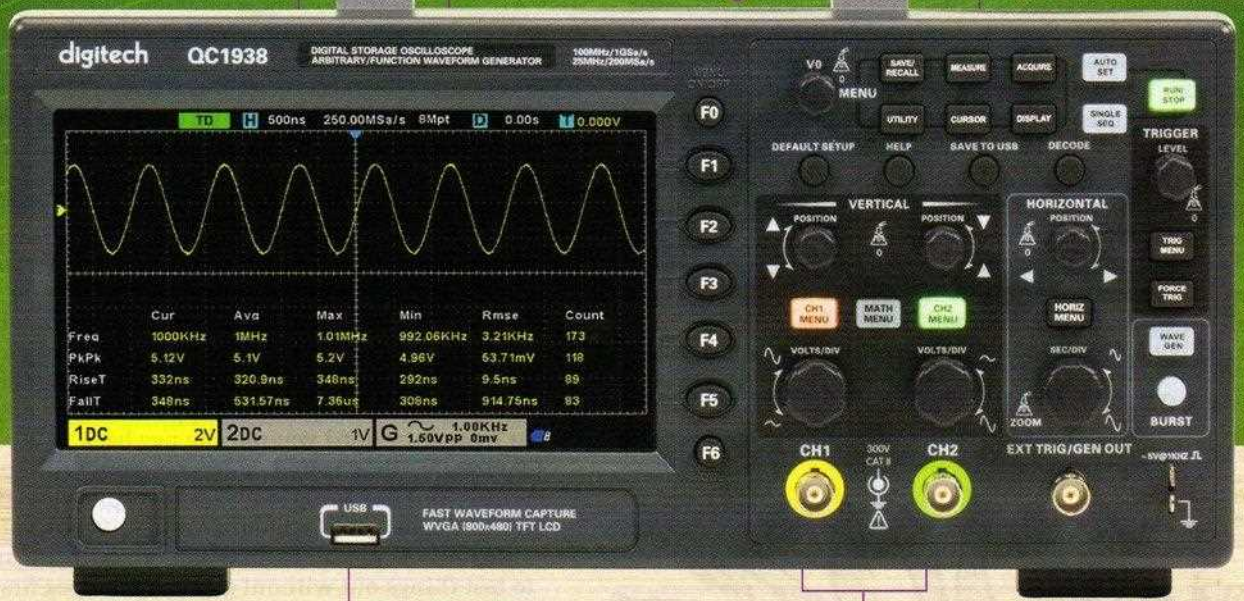

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SERVICEMAN'S LOG

Neighbourhood network noise

Dave Thompson

This story isn't about an electronic device that needs to be fixed; instead, it is about some neighbours who needed to be 'fixed' and an electronic device might have been the solution. These neighbours liked to make a lot of noise, and my long suffering friend thought that some electronic noise might just shut them up...

Back in the mid-1990s, I had the excellent fortune to visit a pop-up James Bond museum in England. Many of the props and spy devices dreamed up by the fictional Q branch were featured.

That included watches with lasers and retracting garrotting wire, lighters, cuff-links and pens with embedded 'radio transmitters' and 'trackers' as well as other well-known 'weapons' such as Oddjob's steel-rimmed bowler hat, Rosa Klebb's knife shoe, Scaramanga's golden gun and more.

Of course, these are movie props designed to look good on screen, and most don't really work. Still, everybody seems to love this type of thing and I am no exception.

I've made my fair share of 'bugs', trackers, ultrasonic doodads and other gadgets but nothing as far-fetched as those Bond contraptions. These days, however, such things are not so far beyond modern technology.

The other day, I watched a video of European armed forces taking control of an enemy drone and landing it into an allied soldier's outstretched hand. The tool they used looked like a rifle fitted with an antenna array instead of a barrel and boasted several mysterious-looking cowlings hiding the electronics.

The operator simply aimed it at the drone, held it in his 'sights' and brought it into a gentle landing. Incredible!

As it turns out, I'm very familiar with the taking down of airborne vehicles. As an aeromodeller back in the day, I flew many radio-controlled models, and plenty of them were wrecked thanks to idiots accidentally (or deliberately, in one case) turning on a transmitter using the same frequency that I was using.

This confuses the receiver and, as it doesn't know which signal to respond to, it just locks up or twitches uncontrollably, inevitably causing the earth and the aircraft to meet – usually at ground level.

Back then, we used the 27MHz band for model flying (later 35MHz, later still 2.4GHz). Within the 27MHz and 35MHz bands, only a set number of frequencies were allocated to R/C (remote control) use.

Most flying fields and clubs used a 'peg' system; if your radio gear used, say, 27.125MHz, you took the peg for that frequency from the board; while you have that peg clipped to your antenna, nobody else is supposed to use anything on that frequency until you put the peg back.

Obviously, this relied a lot on goodwill, patient queuing and not being stupid; sadly, plenty of people would neglect this system and turn up to the field, unload their model and switch on their transmitter to test things out without grabbing the peg first. The result was usually lots of swearing, some crashes and a firm reinforcement of the flying field rules to the offender.

All you needed to do to ruin someone's day was to sit somewhere within range with a transmitter, turn it on and watch the planes fall. Some miscreants did this for 'fun' or out of spite. You could do the same thing with any type of signal generator that swamped that band; many so-called 'jammers' work this way.

In fact, anything that emits wide-band interference will naturally jam and confuse receivers and transmitters; a big enough spark-eroding machine or a plasma cutter can do it. Dad used to curse VW bugs driving past because the interference played havoc with his CB radios – it seemed no amount of RF

a pop-up James Bond museum

Items Covered This Month

- **Denying the neighbourhood speaker**
- **Fixing two power banks**
- **Replacing an Ozito mower's battery pack**
- **The flat 125Ah lithium-ion battery**
- **Refurbishing a Peak multimeter**
- **The breadmaker with a short fuse**

Dave Thompson runs PC Anytime in Christchurch, NZ.

Website: www.pcanytime.co.nz
Email: dave@pcanytime.co.nz

Cartoonist – Louis Decrevel
Website: loueee.com

suppression stopped the electrical noise from those air-cooled engines!

These days, radio signals are supposedly much more robust and more immune to interference. Still, going by these emerging battlefield videos, signals can obviously be hijacked and the model/drone/UAV taken over to do the interceptor's bidding. It is worrying indeed!

Naughty neighbours need knackering

This rather long-winded introduction is building up to a quandary a friend of mine brought to my attention recently. Like many of us these days, he is suffering from noisy neighbours. While suburban living is always going to have some noise, such as lawn mowers, chainsaws, water-blasters etc, they are usually temporary and sound levels soon drop to birdsong level once the yard work is done.

Apparently, these neighbours place a large Bose wireless speaker out on their lawn and pipe music to it by some means. The sound levels are reportedly rock-concert loud and go on for hours every day and often into the night. That really would be annoying!

My friend was at his wit's end; he'd called the noise control people dozens of times – they seemed to be toothless other than giving the noisemakers a stern talking to. The usual occurrence, once the enforcement people leave, is the music gets turned back on, only louder.

Surely, my friend suggested, I must know of, or could even make something, to fight back against these neighbours. I told him no. Despite being very interested in the technical aspects of any device that might help in this scenario, I wasn't keen to get involved. Creating RF interference on purpose would likely be more illegal than them pumping loud music! Still, it really fired my imagination, so I decided to investigate anyway.

My first thought is that any solution would need to be something that affects only the annoying guys while leaving other neighbours alone. That would likely be almost impossible.

Simply cranking up a guitar amp and pointing it at the neighbour's house while having someone who doesn't play guitar do their best Jimi Hendrix impersonation would undoubtedly be entertaining. It'd also give everybody in the surrounding area cause for complaint!

I admit to doing something similar many years ago when flatting and working nights at the airline. The guy next door had a DKW two-stroke car that he'd fire up at 6.30am and leave idling for 15 minutes to 'warm up' before heading off to work. I asked him nicely several times not to do that, or park it on the road, because I worked nights and got to bed at 5am.

He told me to suck it up, so I started practising guitar playing when I got home at 4am, with my amp perched on my bedroom windowsill, pointing directly at his bedroom window across the drive. Even at low volume, he would have heard it clearly. He got the message.

While getting revenge like this is nice to imagine, it is far too indiscriminate in suburbia. If only there were some way to take control of their system and interrupt it, or turn it down ourselves.

I knew of nothing that would achieve that goal. I suppose that some sort of jamming device might be able to disrupt the signal; I've noticed mobile phone jammers advertised on the likes of AliExpress and eBay, but they are pretty expensive, and jamming is illegal anyway.

By the looks of the blurb on those sites, the jammers can block most bands associated with mobile phone operation, including the 2.4GHz and 5GHz WiFi and Bluetooth bands on some models. I imagine if anyone got caught using one of these in New Zealand, they would risk conviction, seizure of the hardware and incur a hefty fine to boot.

I advised my friend against using such devices for that very reason; besides, it may not even work on their system, and that's a lot of money to throw away for no result. Thankfully, he agreed. Still, this sort of thing is fascinating, a bit like those Bond gadgets; interesting and potentially useful in the right situation!

Creating a 'jam session'

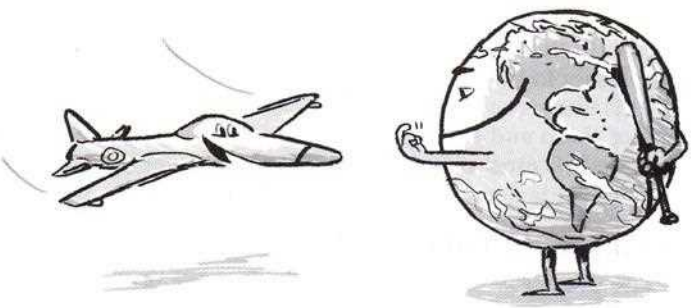
More internet searching revealed several DIY jammers designs, but the assembly and technical details on them were scant. That path looked like a lesson in frustration.

Besides, anything like this could only be purely hypothetical anyway because I didn't know for sure how they were streaming the music to the speaker (Bluetooth, WiFi or even a direct connection). I also really didn't want to get wrapped up in the whole grubby business.

My research took me down a few rabbit holes, though, especially regarding the Bluetooth and WiFi angles. I also learned that the noisy neighbour issue is a global problem, if the number of people posting on forums and asking questions on project pages was any indication.

Some people wondered if a 'shotgun' (hyper-directional) speaker existed (like those shotgun microphones that were all the rage once), but the consensus was 'not really'.

Could something be made to take control of the speaker and shut it off? There are quite a few experimental projects



causing the earth and the aircraft to meet

getting revenge is nice to imagine

along these lines, the downside being that the latest Bluetooth LE (Low Energy) protocol is not compatible with older versions of Bluetooth (and these projects) and is much more difficult to 'hack'.

To have any success, I'd need to know what devices were involved and what version of Bluetooth they used; that avenue was already becoming moot. However, I have plenty of older Bluetooth speakers and headphones around the workshop, and my interest was piqued.

I breadboarded a unit; for obvious reasons, I won't be going into details other than to say I used an Arduino to control it all. I also had to use relatively complex tools on my Linux laptop to 'sniff' for Bluetooth signals in my workshop. Once I identified the correct device, I could try to disrupt or break the connection using the 'jammer' circuit.

While it did work after a fashion, to be truly useful, the transmitter would need to be much more powerful and considerably closer to the receiver to make much of an impact. As it turns out, most Bluetooth streaming protocols are incredibly robust, so this type of exploit would never fly, unless you could 'ring-fence' any potential target with hardware. A good idea then, but busted. My reading led me to another interesting area, though.

People sometimes stream and cast music between devices using their home network and wireless router (some Bluetooth connections also use routers). Someone has created a small project that uses an exploit that still exists in many of today's routers using the 802.11w protocol. Simply sending a 'disconnect' or de-authentication packet to the target router drops off anything connected wirelessly to it.

This idea was too intriguing to pass up. I needed to build one of these and see if it worked – on our own network, obviously – most certainly not to harass anyone else! As they say, this device was for educational purposes only!

Attack of the ESP8266 clones

The project is very well-researched and is now on version 3. It is easily made by anyone familiar with computers and flashing .bin files. It uses a readily available (and very cheap) ESP8266 board, which must be flashed/programmed, utilising easy-to-use (and free) software tools.

Once assembled and up and running, it turned out to be a very stable device, running from a battery pack, a 5V phone charger or a computer's USB port. Power consumption is very low, making it quite portable, so it can be set up anywhere around the house to test how healthy a home network is and whether the router is immune to such exploits.

In general, if your router is more than a year or two old, it likely will be vulnerable to the de-authentication attack. If the router uses the latest WPA3 security protocol, it **should** be immune.

Essentially, the ESP8266 creates a standalone WiFi node and web server, which you can then connect to using a smartphone, tablet, laptop or any WiFi-enabled computer. Once joined, you enter the IP address of the board in your device's web browser, accessing a web-based user interface.

It is surprisingly comprehensive, and it transpires that this device has several other interesting and related functions aside from the de-authentication feature you can test network security with.

I have a drawer full of older but still-too-good-to-throw-away routers gleaned over the years, so I set a couple of them up around the property with easily identifiable SSIDs (network names). I also connected some random WiFi-capable devices to them to test out this de-authentication functionality.

Finding the routers is easy – all wireless networks within range are listed at the click of a button. Usually, the closest networks will be listed near the top; as I used specific SSIDs, it was easy to select the test networks. Once selected, a menu option is selected to carry out the de-authentication attack.

The instant I clicked the go button, my connected devices dropped off the target network. The same thing happened with the other router I set up. I tested a few more of my older routers, and all behaved the same way.

I took the ESP board to the end of my long driveway and tried the attack on the routers I'd set up inside the house from there. Once again, all dropped connections immediately. So it is quite a powerful little device.

While there is provision to add an external antenna on later versions of this board, I found my version 2 setup with a built-in antenna easily picked up routers in households well beyond the boundaries of my back-section property. I could see how this device might easily be misused in the wrong hands.

The big test would be to try it on our main network router, a TP-Link Archer C7 v5. It is old by today's standards, but it has some relatively sophisticated anti-cyber-attack features built in. They are off by default but can easily be switched on via the web interface.

I had to pick my time because my wife works from home and is usually in Teams meetings half the day. I didn't want to knock her connection off during my tests!

When I had a clear run, I tried the attack and sure enough, off everything dropped. The thing with the de-authentication attack is that as soon as the packets are no longer being sent to the router, disconnected devices will usually try to re-establish the connection, so just one little drop-off might not be noticed.

The ESP can be configured to send a continuous (preset)

stream of de-authentication packets to the router, preventing WiFi devices from reconnecting. Nasty!

I tried applying the various anti-cyber-attack settings on the router, but as I suspected, they made no difference for this type of attack. While hiding the SSID (an option on most routers) might help prevent the router from being 'seen' by the ESP, it might also hamper connecting to it if you allow people to use your router's WiFi connection.

Upgrading to a new router should prevent most attacks of this type. I have one on order! All in all, it is a fascinating, functional gadget and strangely satisfying to build and test. For educational purposes only!

Fixing two power banks

B. P., of Dundathu, Qld will repair anything that isn't working correctly. This time it's a prevalent problem: over time, USB sockets on cheap devices can detach from the PCB and become intermittent...

I have had two small power banks for several years. They came in very handy recently for charging our phones when our power was cut due to flooding in this area. Both power banks worked well to charge our phones, and we were recharging them from our car's USB port.

I noticed that the green power bank had a problem with the charging cable, which seemed to be loose, and it was necessary to push the cable to one side for the power bank to charge.

After the power came back on, I looked closely at the faulty power bank to determine if it could be easily disassembled. It appeared that the white top was an insert that I could remove. I was then able to extract the PCB and battery.

On close inspection, I could see that the micro Type-B USB port's two power pins were no longer attached to the circuit board, and the two shell pins were very loose. The problem was that access to the tiny pins was very limited; it would be a challenge to re-solder the pins with a regular soldering iron.

There was nothing for it but to try to re-solder the pins and hope that I didn't destroy the power bank. I had a close look at how to get the tip to the pins without burning anything nearby. This was like trying to remove a splinter with a crowbar.

I tried to re-solder the two power pins first; then, I plugged in a charging cable to test the repair. The first attempt was unsuccessful, and the charging light did not come on. The second attempt proved to be more successful, with the charging light now coming on, so I re-soldered the two shell pins and plugged the charging cable in again to ensure that everything was still OK.

This power bank is just a small one that uses an 18650 (18mm diameter, 65mm-long) Li-ion cell. The fact that it can be easily dismantled for repair means that the battery could be replaced if it came to the end of its life and the power bank still worked. Another successful repair enabled the power bank to continue its useful life.

Replacing an Ozito lawnmower's battery pack

R. S., of Figtree Pocket, Qld is a prolific contributor and he has been busy replacing rechargeable batteries in various devices...

Ozito no longer supplies 36V mower battery packs and instead uses two 18V packs on their electric mowers because 18V packs are used for their other tools. So if you have one of these mowers and the battery fails, you either have to repack the battery or replace the mower. The packs use 20 18650 lithium batteries in parallel pairs, with 10 pairs in series to get 36V.

As newer lithium-ion cells have a higher mAh capacity (3400mAh), I decided to use just 10 cells in series. I purchased four Samsung 18670s at $9 each from eBay and six Panasonic NCR18650B at $15 each, both from Australian suppliers. Buying from overseas is impractical due to transport difficulties or high delivery costs. I mainly used two different battery suppliers to compare them.

There is no battery balance circuit in the packs. If some cells are already charged to 4.2V, charging is terminated too early, as the fully charged cells go open-circuit due to their inbuilt safety valve. So for the charger to charge all cells properly, the cells should all start with the same voltage (eg, 3.6V).

The Ozito charger charges at 1A, taking about three hours to fully charge the battery pack. There is a 0.1Ω current-sensing resistor in the charger, which usually has 0.1V across it. If you prefer a slower charge rate, you can change the resistor to 0.33Ω to reduce the charging current to 0.3A.

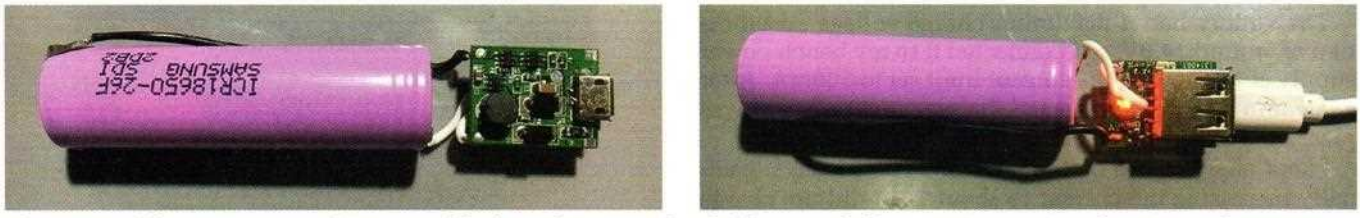
I repacked a 36V Ozito mower pack with ten Panasonic NCR18650B cells in 2017, and it is still working. With a 15Ω test load, the voltage drops from 41.5V to 39V, showing an internal resistance of about 0.9Ω. The mower won't run with the pack with mixed cells – it has a higher internal resistance of around 1.3Ω.

The NCR18650B cells I recently received can deliver less current (9A) than the ones I used to repack my first battery. It seems that the design has changed, or the ones I used this time are not genuine.

Some Samsung cells have an electronic current limit (at the negative end), limiting the current to about 9A, but by removing it, the limit can be increased to about 20A.

The cells with the electronic current limiter are a bit longer and have a copper strip down the side connecting positive to the circuit. I decided to repack the second battery with all Samsung cells this time due to their higher current limit.

After swapping the second battery pack to all Samsung cells, it is now working. Paying extra for heavy-duty cells in the first place would have saved a lot of time, but my



The PCB and battery was easily extractable from the power bank (shown at left); upon inspection, the USB socket's two power pins were not attached. After resoldering those two pins it eventually powered up succesfully (shown at right).

first repack with the NCR18650B cells in 2017 worked with no problems, so I expected the same this time.

Another problem with repacking is that new cells may be longer than 65mm. For example, the Samsung cells I purchased are 67mm long. They would not fit in a Deebot DN5G robot vacuum cleaner, while in a Samsung SR8980 robot vacuum, there is plenty of room as the original battery was in a plastic case.

The large cells used in the Dyson V11 vacuum are 20700 (2mm larger in diameter and 7mm longer), making them difficult to reuse if space is limited.

I am soldering the cell terminals (they don't come with solder tags). It seems to be easy to solder the negative end, but not the positive end, which I think is stainless steel. I bought some special liquid flux which helps. I also find that I also have to sand the positive terminal to get the solder to stick.

However, one cell positive terminal would not take solder. When I get my spot welder, I will try that. In the meantime, I had to use another cell. Another new cell reads open circuit; perhaps the protection valve is faulty.

Editor's note: don't mix Li-ion cells; use all the same type and age, especially in cases like this where there is no balancing circuitry.

A flat 125Ah lithium-ion battery

D. M., of Toorak, Vic saved his friend a lot of money with a trivial repair, when the manufacturer wasn't all that helpful...

I have a friend with a 4WD that has an auxiliary 125Ah lithium-ion battery with Bluetooth monitoring and a nominal voltage of 12.8V. It retails for a cool $1890. He uses it to power the vehicle fridge/freezer, which he keeps running whether the vehicle is in use or not. The battery is charged via the vehicle alternator.

He was understandably rather upset when the battery apparently went flat, and the dedicated charger connected to the alternator would not charge the battery. Some chargers will not charge a very flat battery for safety reasons.

He bought it to me, and I measured the terminal voltage at 1.9V. A call to the manufacturer's representative resulted in them advising that the battery was almost certainly destroyed at such a low voltage.

I told them that I thought these batteries had an internal battery management system (BMS) that would shut the battery down. In fact, the specifications say there is a low-voltage cutoff of 10V. The representative said the BMS did not always shut down the battery at low voltage, and its primary purpose was to manage the battery charge and discharge rates relative to cell balance and temperature.

My friend independently called another branch of the manufacturer and was told they would take a look at the battery for a fee of $250 plus return freight between Melbourne and Sydney.

The battery had a maximum charge voltage specification of around 14.6V, so I connected it to my bench power supply at 13.5V with the current limit set to 500mA. After a few minutes, I disconnected the power supply and was pleasantly surprised to get a reading of about 13.3V.

I kept charging the battery for the next few days, gradually increasing the current to about 1A. I did not charge the battery fully because I could not tell the state of charge, as I could not connect to the battery's Bluetooth system, which would give such information. In any case, I disconnected the power supply and the voltage held constant for a couple of days.

I reinstalled the battery in his vehicle and, using a clamp ammeter, measured the charge current when the vehicle engine started as 40A. The battery can accept a 100A charge current. I told my friend to keep the battery on float charge via a dedicated charger if he wants to keep the fridge running when the vehicle is not in use. The recommended float charge voltage for that battery is 13.8V.

My conclusion is that the BMS disconnected the battery from the terminals to protect it when the voltage reached the 10V threshold below which the battery could be damaged. The charger refused to charge it because the disconnection meant the terminals only presented 1.9V. As soon as I put a small amount of charge in it, the BMS reconnected the battery, and it could be charged normally.

The manufacturer representatives seemed unaware of this possibility. My friend reports no further problems with the battery, and he is pleased I saved him $1890.

You can see some pretty good photos of what the BMS circuitry looks like in a battery this large at the following website: siliconchip.au/link/abhr

Refurbishing a Peak multimeter with new batteries

R. E., of Majors Creek, NSW 'fixed' his multimeter by making up a new battery (with the original type no longer available). But with the simple repair comes an interesting story of the past...

In the early 1970s, I obtained my first multimeter – a Peak OL-64D (Hioki Electric Works). I have used it extensively over the last 50 years. When I recently used it on the ohms range, the needle didn't move because the AA cells were flat and had corroded the terminals. The 22.5V battery, which I suspect was original, was also flat.

22.5V batteries haven't been made for years, so I planned to use two small 12V batteries in series with some series diodes added if the exact voltage was critical. I soldered together the batteries and soldered wires to the meter

The front view of the Peak OL-64D multimeter.

terminals. I wound the ohms adjuster pot anti-clockwise in case the higher voltage caused the pointer to overshoot.

To my astonishment, the pot could only adjust the zero a short distance up the scale. Wondering if my quick soldering had damaged the batteries, I checked the voltage with another meter. Surprise: only 3V! A close look at the batteries showed I had used N cells rather than the 12V A23 'lighter' type, which are much the same size.

After uttering some naughty words, I de-soldered the N cells and reconstructed the battery with two of the more suitable A23 batteries. The zero pot had plenty of range, and the x10,000 range worked again.

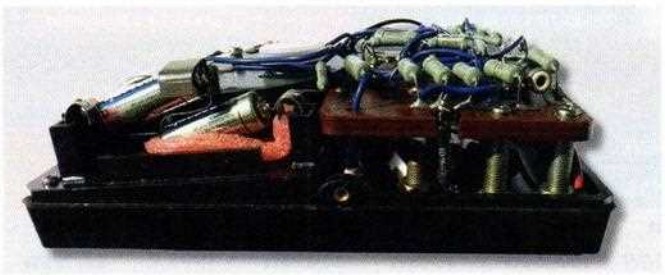
In the 1970s and 80s, I worked at the NASA Orroral Valley Tracking Station on Operations. Occasionally, when major equipment changes were scheduled, the operational shift workers would be temporarily reassigned to other 'day work' at the station. In 1980, I had a week in the Test Equipment Lab, properly called the Precision Measuring Equipment Laboratory (PMEL).

Dave (different from the Serviceman), the Senior Technician, was ex-Army, versatile and competent at maintaining the station's master standards. He had a laconic sense of humour and a sensitive BS detector.

Several times per year, American-based engineers would visit the station bringing 'traceable' (NBS became NIST in 1988) transfer standards on their flights to check the calibration standards held in the PMEL. Many of these engineers took their jobs with deadly seriousness. Some may have been recruited from regions where humour is unknown.

There was a complicated paper trail of visit dates, equipment calibrated, discrepancies found etc. As well as using their signatures, these engineers all had personal rubber stamps that they kept secure so that no one else could use them.

They would prepare the paperwork, get Dave to sign in the right place and then ask him to apply his stamp. Sometimes for impact, he asked them if they were sure. He would then stamp a red 'rubber duck' on the forms. Some were horrified, feeling that it diminished the importance



The side view of the Peak OL-64D multimeter and NASA PMEL Cal sticker.

regions where humour is unknown

of their own stamps, their jobs and probably themselves.

I'm glad I still have my meter with its 1980 NASA PMEL Cal sticker – complete with Dave's initials and red duck stamp (see photo at lower left). RIP Dave.

The short-fused breadmaker

K. W., of Craigburn Farm, SA likes to make his own bread but was frustrated by the breadmaker playing up. Luckily, it turned out to be a simple fix...

I've had a few breadmakers over the years; they don't last forever. My Panasonic SD-2501 model has been the best yet, and its bucket and paddle are still in good nick, so I was perturbed when it started playing up. Twice it failed to bake after mixing, forcing me to complete the loaves in the 'normal' oven. Then it stopped powering up altogether.

I pulled it apart to see if I could find an obvious fault. It is well made and opened up reasonably easily. I found no obvious failures, no burnt smell, no shonky connectors and heater element showing a fair resistance. So I started tracing the power feed. Sure enough, an over-temperature fuse (of two) in the supply line was open circuit.

I sourced a replacement from Jaycar, getting the next temperature range up since they didn't have the exact one. The hardest part of the whole process was prising the crimps open, pushing in the new fuse and re-crimping it. I just used pliers since I don't have a flash crimp tool.

I switched it on, and it was all good. So my favourite breadmaker was saved from the dump and is still working well. I think what blew the fuse was loaves that rose too high and blocked the heat vents in the lid. Too much water or yeast can cause that. I'll be more careful from now on.

I've kept our nice Panasonic microwave oven from the dump too. After a loud 'pop', it ceased heating. All inside looked OK, so I gambled on the klystron, buying a replacement online. Not an exact match, but it worked. The microwave lives on.

Appliance failures are inevitable, but sometimes a simple look inside can reveal an obvious fault that's easy to fix and much cheaper than replacing the whole thing. SC

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Tip Temperature	450°C	450°C	450°C	450°C	580°C	580°C	**580°C**	**580°C**	**580°C**	**580°C**
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Power	25W	20/130W	6W	30W	30W	30W	40W	**80W**	15W	30W
Temperature	380°C	420°C	430°C	200-450°C	470°C	430°C	420°C	**530°C**	320°C	**600°C**
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HIGH-END

PART 2: BY PHIL PROSSER

ACTIVE MONITOR SPEAKERS WITH SUBWOOFER

The Active Crossover Amplifier fits in a clean-looking black metal case and contains everything you need to drive the Active Monitor Speakers presented last month. It could also be used to power a different two-way bi-amplified speaker system with or without a subwoofer.

You will have heard us discuss active speakers and their benefits before. One of the problems with them is that if you use standalone parts, you end up with a stack of boxes containing preamplifiers, crossovers, power amplifiers and speaker protectors. The result can deliver excellent performance but can also be an unruly mess.

This article will describe how you can fit all the required electronics into a svelte two-rack-unit (2RU) high case, offering 50W per channel for each midrange/woofer and tweeter, with line level outputs for an active subwoofer or two. A high-quality matching subwoofer will be described next month that can deliver substantial, clean bass down to almost 20Hz.

An output power of 50W for the midrange/woofers and treble drivers might seem modest, but there is also a 180W amplifier in the subwoofer, giving a total system power of 380W. 50W is actually an enormous amount of power for the other drivers as these amplifiers do not need to handle the large voltage swings required to deliver the bass (any signals below ~85Hz).

This article brings together several previous projects; in terms of electronics, we are only adding a very simple power supply board. I have worked to keep metalwork to a modest level of complexity, though some drilling and filing will be necessary.

I built it in a high-quality Altronics H5038 case as this avoids the hassle of fabricating the enclosure and provides enough space to fit all the parts. To start building it, gather or make all the required sub-assemblies, as shown in the panel at lower left.

The input to the Active Crossover Amplifier is the stereo output from your preamplifier, with line level outputs to your active subwoofer and speaker level to the midrange/woofers and tweeters. The Active Crossover Amplifier is the heart of the High-End Speaker System, as shown in Fig.1 from last month.

A full description of each subsystem is provided in the referenced articles. I suggest you read them as they provide good background information that I won't repeat here. The metalwork and subsystem integration forms the majority of this project.

Let's start with building the case, as once that is done, the modules drop in, ready for wiring. You can see the overall arrangement in the adjacent panel and Photo 9 overleaf.

What is needed to build a stereo Active Monitor Amplifier system

4 x Hummingbird Amplifier Modules – *December 2021; siliconchip.au/Article/15126*
3-Way Active Crossover – *October-November 2021; siliconchip.au/Series/371*
Multi-Channel Speaker Protector (4-CH) – *January 2022; siliconchip.au/Article/15171*
Active Monitor Speakers Power Supply – *described in this article*
2RU rack case, heatsink and other miscellaneous parts

Chassis and metalwork

Start by marking and drilling the base of the chassis as shown in Fig.17. Also drill and file the front and rear panels as shown in Figs.18 & 19. Test-fit the connectors and other items to ensure you won't need to rework anything. On the front panel, be careful to check the height of your PCB standoffs, as these determine the location of the holes for the crossover controls.

For the front panel, you will be best off installing the 35mm standoffs at both the front and rear locations of the

Features & Specifications

- Stereo three-way active crossover with 24dB/octave Linkwitz-Riley roll-off
- Four 50W high-fidelity amplifier channels
- Line-level subwoofer outputs (left and right or dual mono)
- Speaker protection and de-thumping on all outputs
- Baffle step correction implemented at line level
- Fits in a high-quality, two-rack-unit (88mm high) case
- Silent operation with passive cooling

crossover board and sliding it forward to verify the drill holes match up with the height of the potentiometer shafts on the crossover.

There are small locating pins at the bottom of the potentiometer mounting threads. The best thing to do is use a 3mm drill and drill a 'blind hole' into the rear of the front panel deep enough to accommodate the pin without going right through the panel. This is not as hard as it sounds, but if you are concerned, filing, cutting or snapping these off is a cheeky alternative.

Slide the crossover in and check the alignment with the holes in the base. Mine were very close. If there is a minor misalignment, it is fine to drill the mounting holes in the base out to 4 or 4.5mm, which will give you wiggle room with the standoffs. I did not install the front standoffs on the Active Crossover board as they interfere with the lip on the front panel.

Now is a great time to drill and tap the heatsink, as shown in Fig.20. There are not that many holes, and the holes line up with the gaps in the fins. If you cannot tap these holes, it is possible to run long M3 machine screws or bolts through the heatsink, but I found that tapping the holes was easy enough and took less than half an hour. To tap the holes, drill to 2.5mm diameter and use an M3 × 0.5mm tap with plenty of lubricant (light oil).

Amplifier construction

If you haven't already, assemble four Hummingbird amplifier modules as described in the December 2021 issue (siliconchip.au/Article/15126). It is important that you attach the wiring before mounting them on the heatsink; once they have been installed on the heatsink, you will not be able to get a screwdriver in to tighten the terminals.

I used 300mm lengths of heavy-duty (7.5A rated) red, green and black wire and a 500mm length of white wire (for the positive, ground, negative and

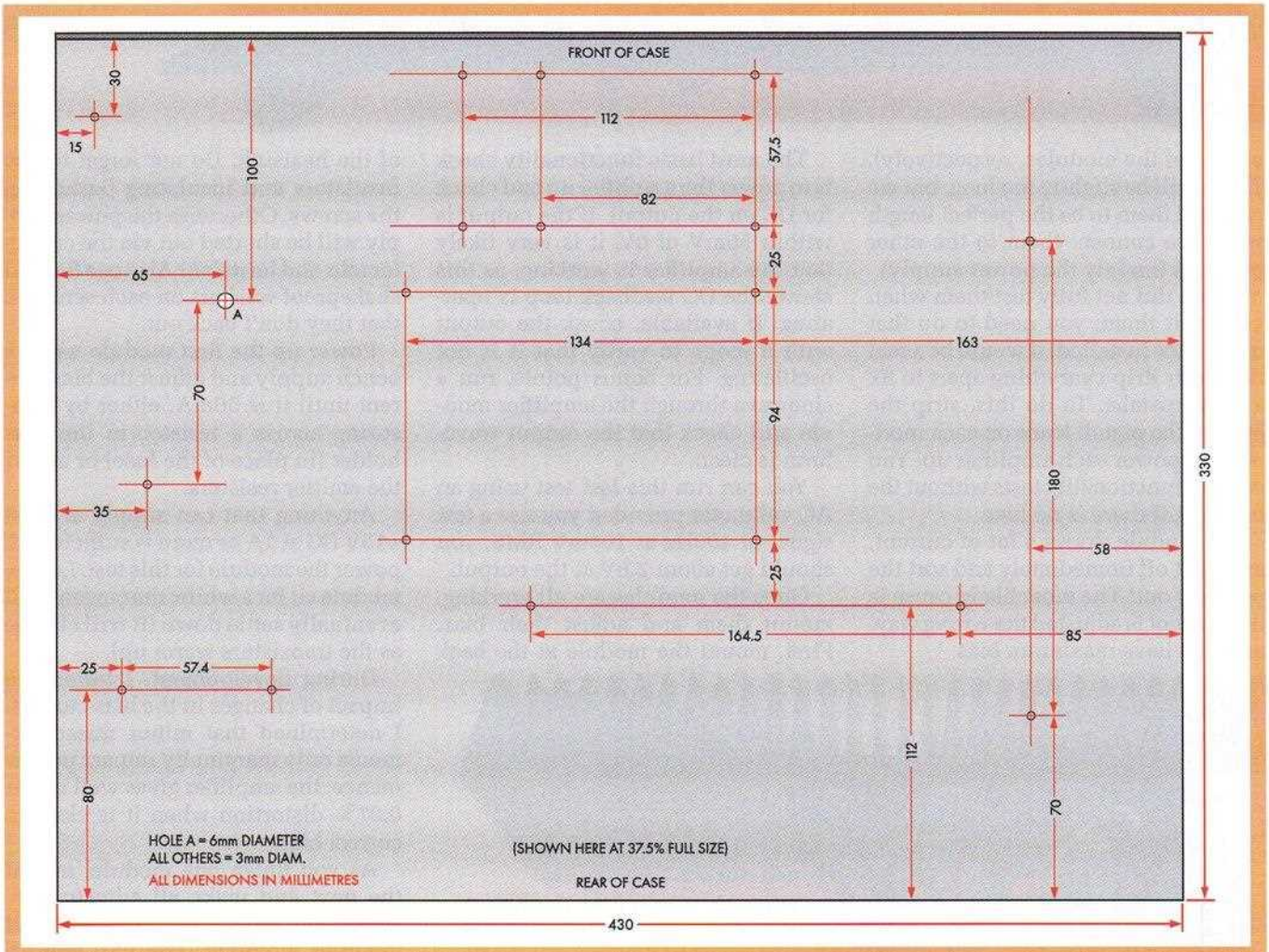

Fig.17: mark & drill the base of the Altronics 2RU case as shown. Drill the holes to 3.5mm for mounting locations; if you need extra wriggle room, you can drill or file them to 4mm. If using a different case, you will have to make adjustments.

Photo 9: When you have built all the modules, installed them in the case and wired everything up, it should look like this. I put a fair bit of effort into keeping all the wiring neat as it helps with the performance. In particular, keep those AC loops tight and away from the Crossover.

output of the modules, respectively). These will be slightly too long, but we can trim them to be the perfect length when we connect them to the other modules (mainly the power supply).

If you did not fully test them when you built them, you need to do that now. Once installed, it would be a real bother to strip everything apart to fix a silly mistake. To do this, strip the ends of the pigtail leads on each module and power each amplifier up. You can run functionality tests without the heatsink if there is no bias.

If a module draws a lot of current, switch it off immediately and sort the problem out! The most likely cause is that the pot is adjusted the wrong way, and you have maximum bias.

The most basic functionality check is to power the amplifier up and check for DC on the output. If the output is within 50mV of 0V, it is very likely that the amplifier is working, as this shows the DC feedback loop is operating. If available, check the output with a scope to verify that it is not oscillating. For bonus points, run a sinewave through the amplifier module and check that the output waveform is clean.

You can run this last test using an AC voltmeter provided you use a test signal of 400Hz at 100mV RMS; you should get about 2.8V at the output.

Once the modules are all working, mount them and adjust their bias. First, mount the module at the back of the heatsink. Do not forget to use insulators and insulating bushes on the screws. Otherwise the power supply will be shorted out via the collector tabs and heatsink! Also use flat and shakeproof washers on each screw so that they don't back out.

Power up the first module using a bench supply and adjust the bias current until it is 50mA, either by measuring across a resistor in the fuse holder (in place of the fuse) or across the emitter resistors.

Anything that can supply at least ±15V DC at 1A or more is sufficient to power the module for this test. Let the module sit for a while; the current will eventually settle down (it will change as the transistors warm up).

During development, I tested the impact of changes in the bias current. I determined that minor misadjustments only marginally impact performance; the amplifier gives well under 0.01% distortion when it is close to correct bias.

As you finish one module, mount the next and make all adjustments. Rinse and repeat until you have all modules mounted. You will end up with an assembly like that shown in Photo 10.

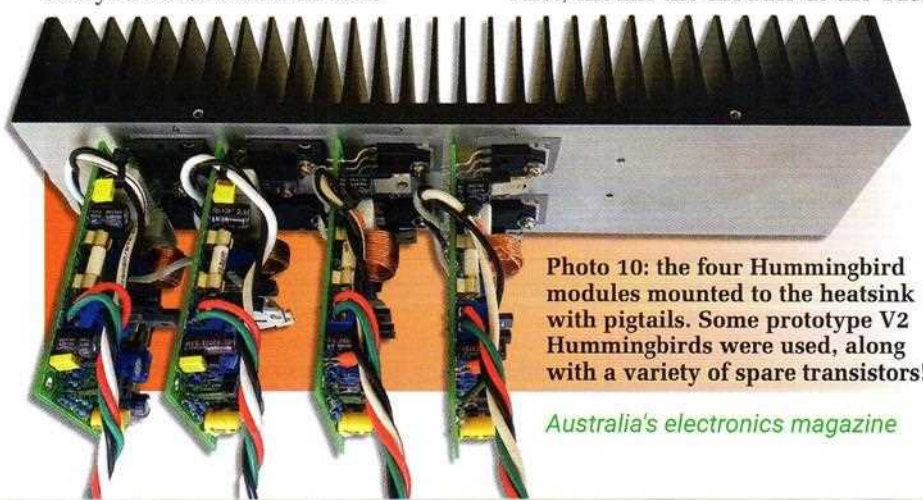

Photo 10: the four Hummingbird modules mounted to the heatsink with pigtails. Some prototype V2 Hummingbirds were used, along with a variety of spare transistors!

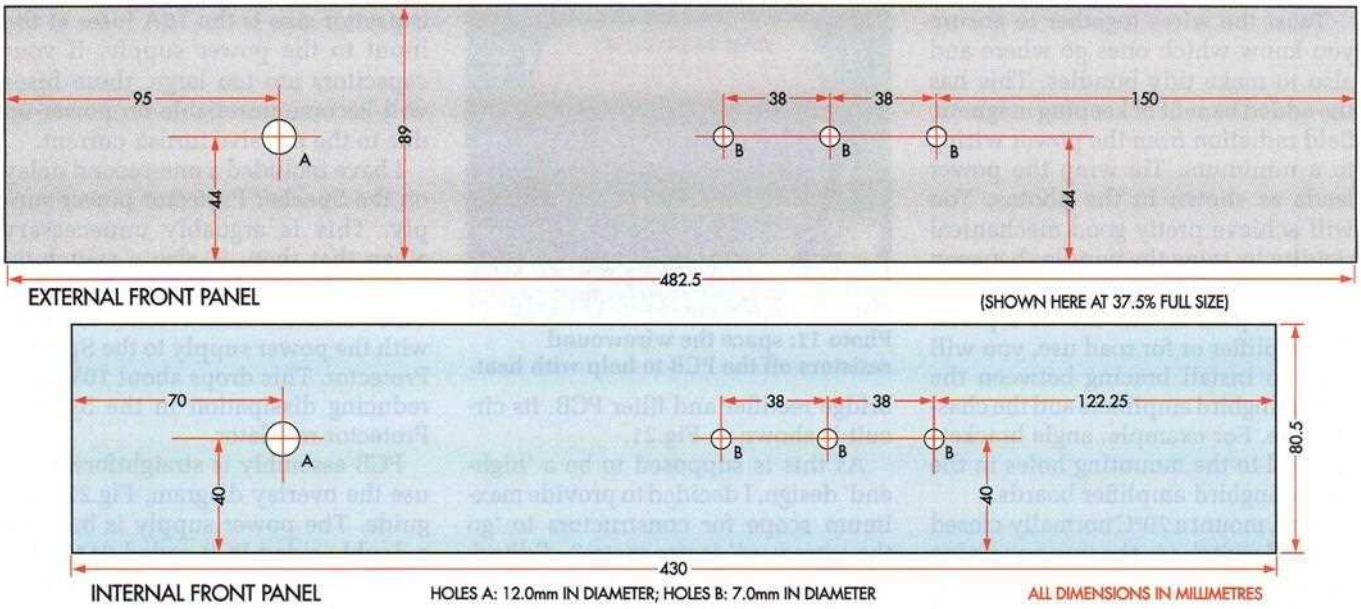

Fig.18: drilling details for the front panels. These are outside views. If drilling a different case, you can use the same general pattern, but you might need to adjust the overall position of the template.

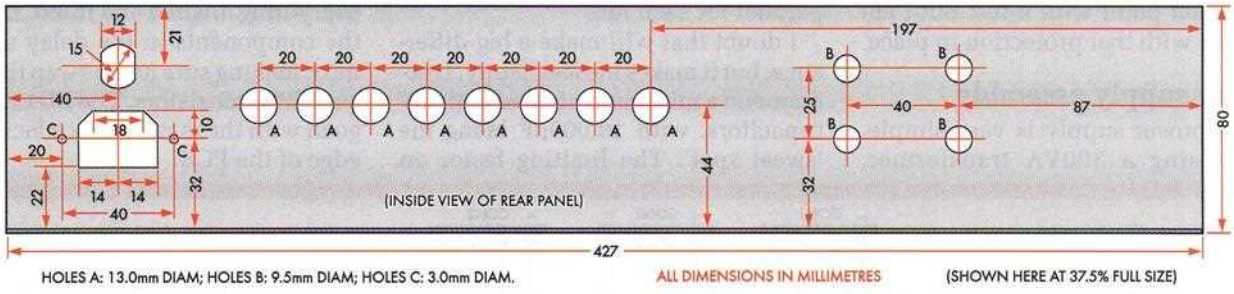

Fig.19: the amplifier rear panel drilling details – note that this is an inside view.

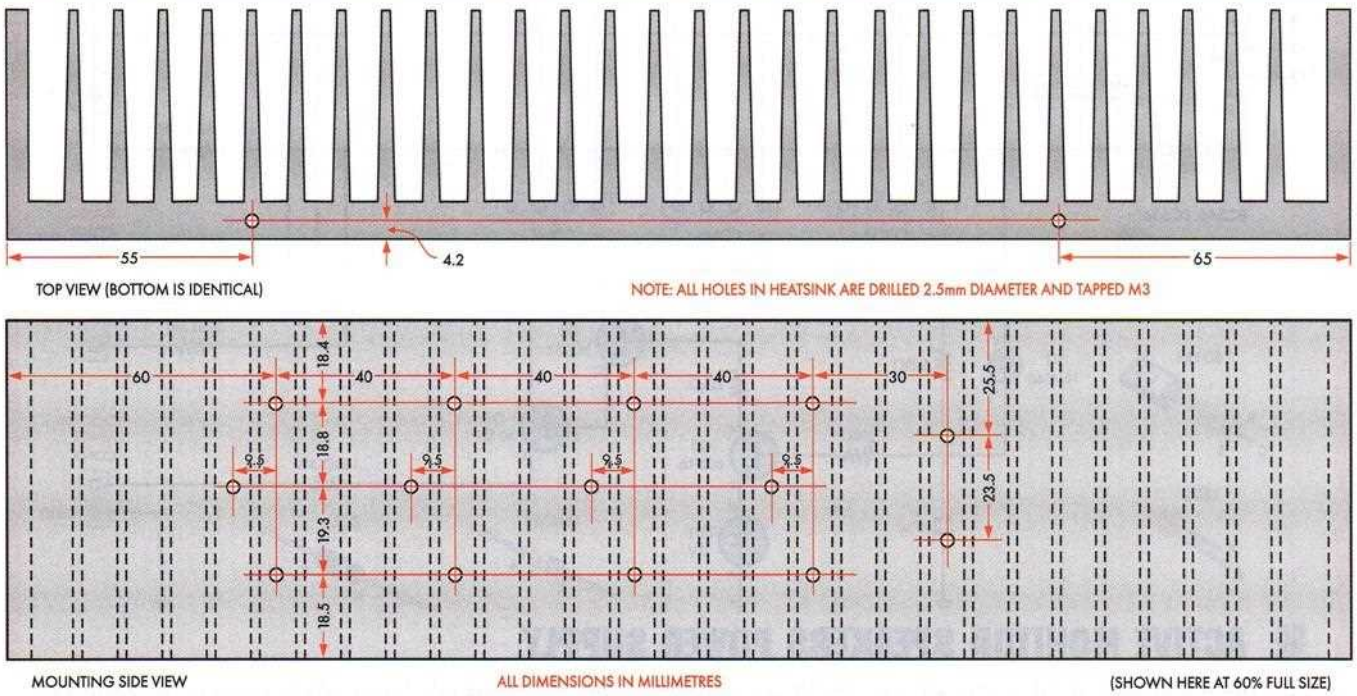

Fig.20: each set of three holes on the heatsink is for mounting one Hummingbird amplifier, with two more holes for the thermal cut-out. Drill and tap at least two holes in the bottom of the main section to mount it to the base of the case.

Twist the wires together to ensure you know which ones go where and also to make tidy bundles. This has the added benefit of keeping magnetic field radiation from the power wiring to a minimum. Tie wrap the power leads as shown in the photos. You will achieve pretty good mechanical rigidity by tying the bundles between adjacent modules.

If you plan to use this as a portable amplifier or for road use, you will need to install bracing between the Hummingbird amplifiers and the chassis base. For example, angle brackets secured to the mounting holes in the Hummingbird amplifier boards.

Next, mount a 70°C normally-closed thermal switch via the two remaining holes on the heatsink, with flat and shakeproof washers on each screw. I have included this as a safety measure – if the heatsink gets too hot, it will switch off. I have never managed to get to that point with mine, but I am happier with that protection in place.

Power supply assembly

The power supply is very simple, comprising a 300VA transformer,

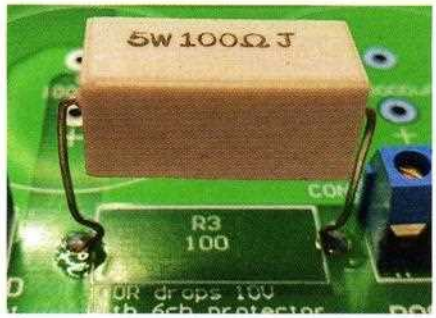

Photo 11: space the wirewound resistors off the PCB to help with heat.

bridge rectifier and filter PCB. Its circuit is shown in Fig.21.

As this is supposed to be a 'high-end' design, I decided to provide maximum scope for constructors to 'go the extra yard' *[extra metre? - Editor]*. My original power supply accepted 10,000µF capacitors. I tweaked this to fit 35mm diameter capacitors, and as seen in the final pictures, that allows me to fit three 15,000µF capacitors in parallel for each rail.

I doubt that will make a big difference, but it makes me feel happy. I recommend a minimum of three 6,800µF capacitors, with 10,000µF being the 'sweet spot'. The limiting factor on capacitor size is the 10A fuses at the input to the power supply. If your capacitors are too large, these fuses will become unreliable on power-up due to the massive inrush current.

I have included a one-second delay on the Speaker Protector power supply. This is arguably unnecessary given that there is also a switch-on delay built into the Speaker Protector. There is also a 100Ω resistor in series with the power supply to the Speaker Protector. This drops about 10V, thus reducing dissipation in the Speaker Protector regulator.

PCB assembly is straightforward – use the overlay diagram, Fig.22, as a guide. The power supply is built on a double-sided PCB coded 01112221 that measures 147 × 60mm.

Start by fitting the screw terminals, then the fuse clips and fuses. I put a fuse in the clips and soldered the assembly in from the top, ensuring everything aligned and fitted. Load in the components in the delay section next, making sure not to swap the PNP and NPN transistors. The BD139 must go in with the metal surface facing the edge of the PCB.

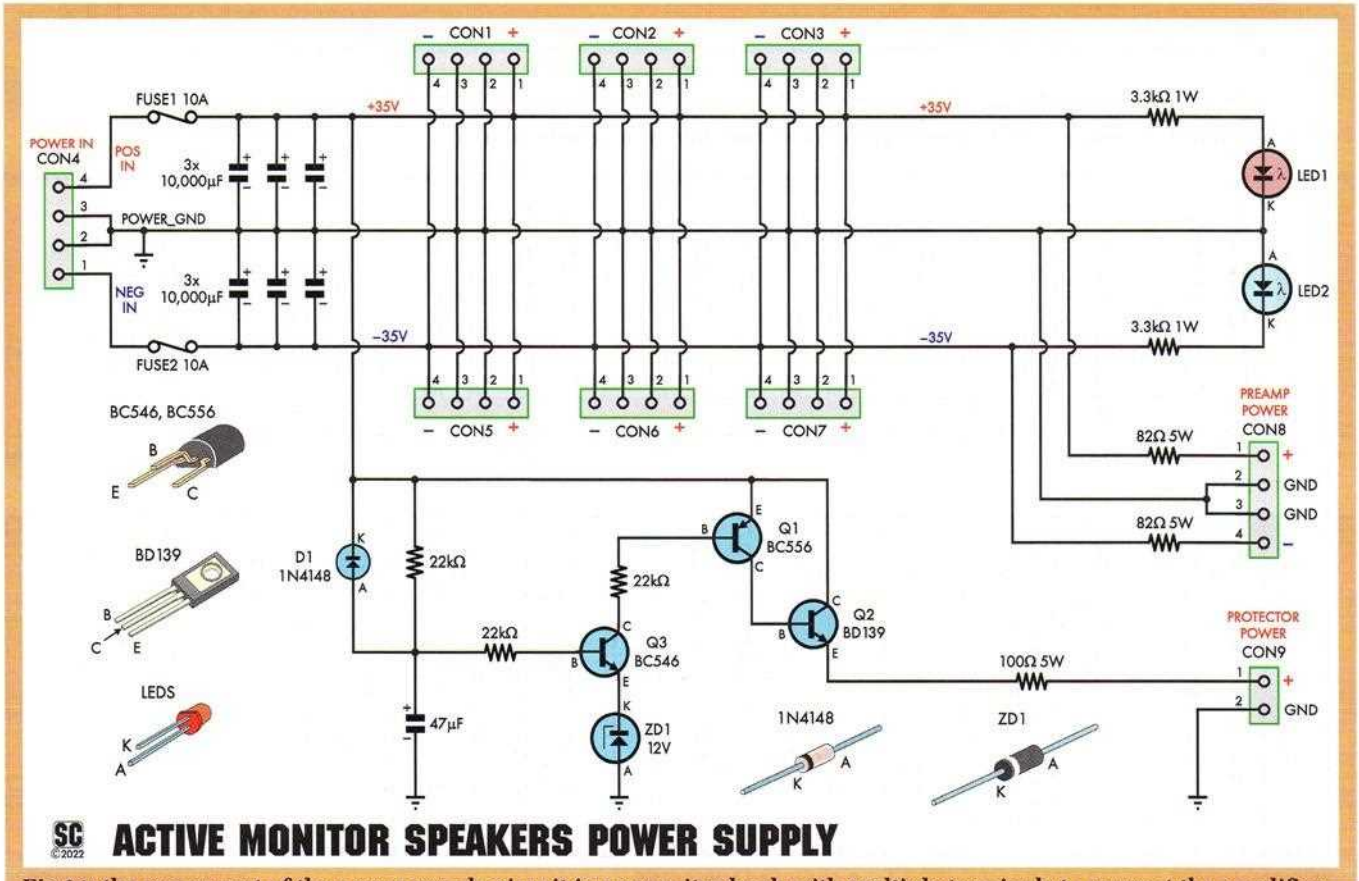

Fig.21: the upper part of the power supply circuit is a capacitor bank with multiple terminals to connect the amplifier modules, fuses for protection and LEDs to indicate when power is present and act as bleeders. The lower part is a delay circuit that applies power to the Speaker Protector after roughly one second.

The 3.3kΩ resistors have a maximum dissipation of 380mW with the nominally ±35V supply rails, so 1W resistors are OK, provided you space them at least 5mm off the PCB.

The 100Ω 5W resistor for the speaker protector runs quite warm to the touch, dissipating about 1W. The 82Ω 5W resistors for powering the Active Crossover drop about 10V and dissipate 1.5W. This might be much less than their 5W rating, but they still get very warm. Stand all these resistors off the PCB by 10mm, as shown in Photo 11.

Mount the power supply board in the case using tapped spacers and machine screws with flat and shakeproof washers. When doing the wiring, do not place plastic insulation wiring against these resistors. The final power supply board, as presented here, moves these resistors away from the power amplifier boards to make that easier.

Powering the Active Crossover

At this point, it will save you a lot of fiddling to connect 500mm of twisted red, green and black light-duty hookup

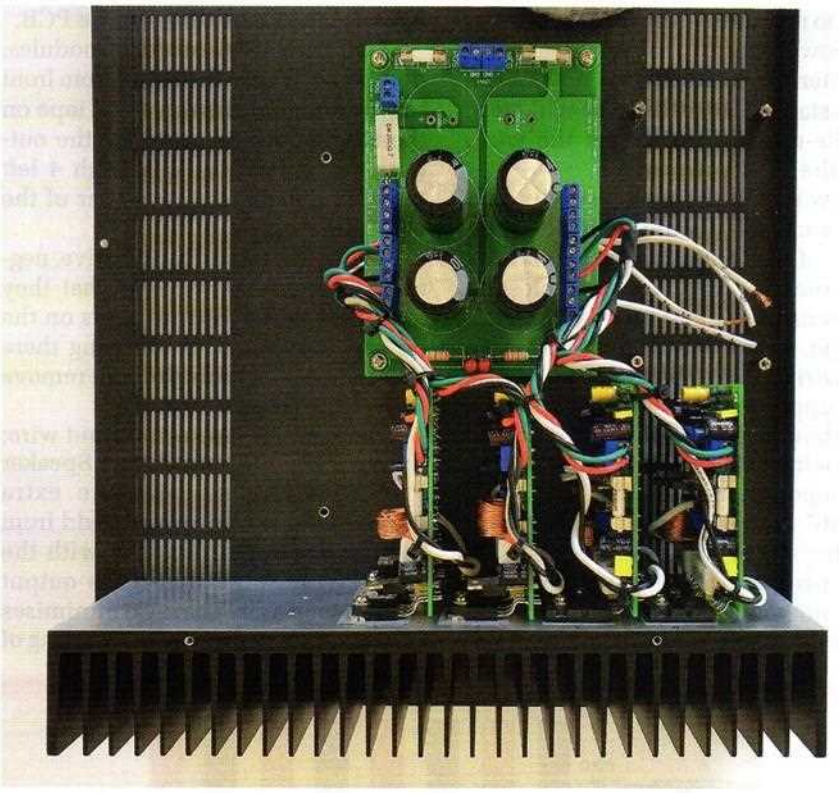

Photo 12: the four Hummingbird amps are now wired up to the power supply, and the output wires running under it are ready to attach to the Speaker Protector. Note that this is not the final power supply board design.

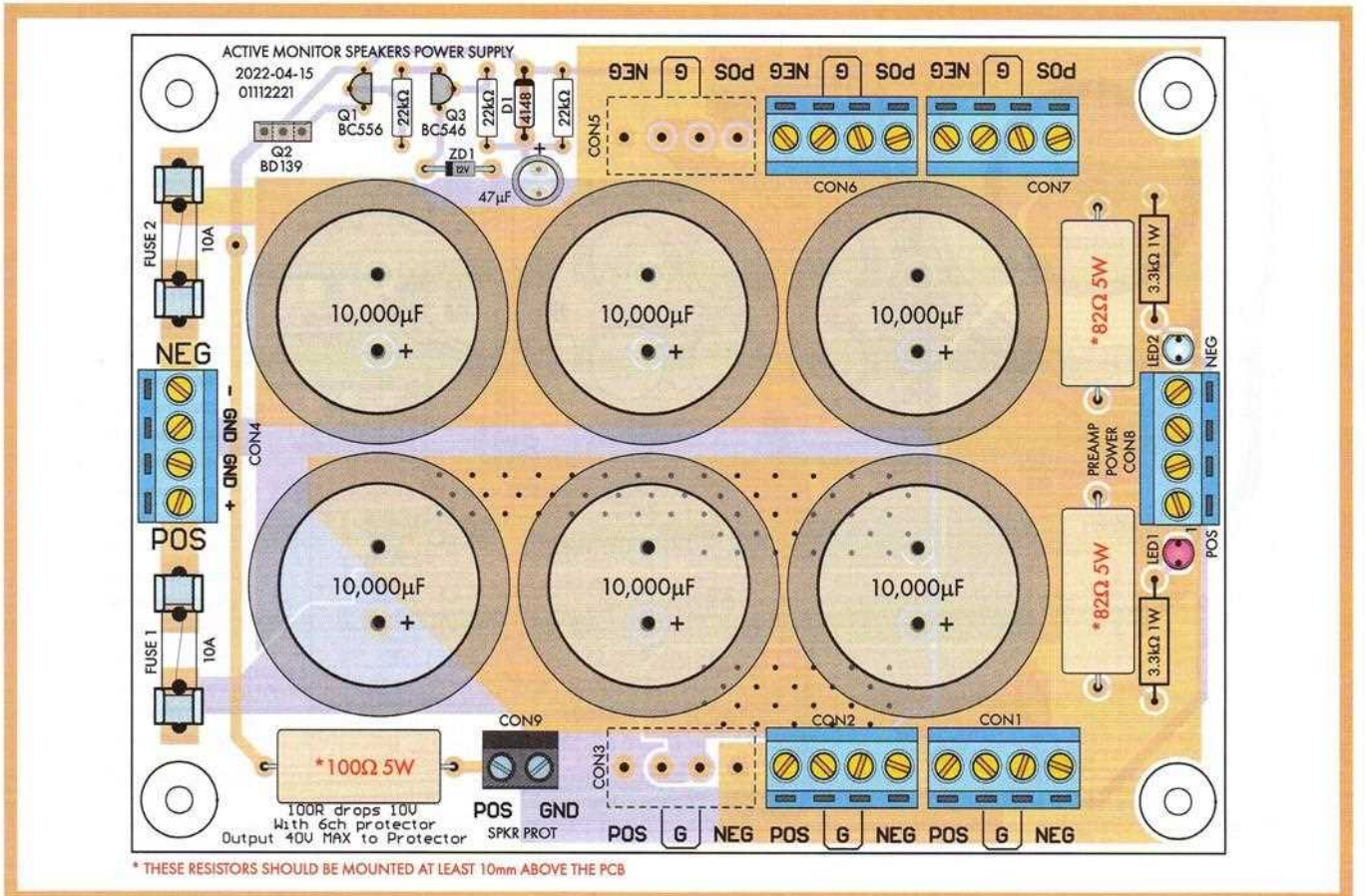

Fig.22: use this PCB overlay diagram as a guide to fit the components on the power supply board. Be very sure to get the electrolytic capacitor polarities right, or it could fail spectacularly!

wire to the Active Crossover header on the power supply board and leave this for later. If you forget this now, it can be installed later, but you will need needle-nosed pliers to get the wires into the terminals.

Now mount the power supply PCB in the case. It should be about 5mm clear of the Hummingbird modules horizontally, with DC input close to the transformer and rectifier.

Next, we need to connect the amplifier wiring to the power supply. The DC supply and mains wiring details are shown in Fig.23. I chose to run one pair of amplifiers from each side of the power supply PCB.

Note that there are output headers for up to six modules, but we only need four in this application. It does not matter which terminals you use as they all connect to large low-impedance copper fills on the PCB.

I kept track of the amplifier modules, numbering them 1 through 4 from front to rear of the heatsink. I used tape on the twisted bundles and for the outputs, ran amplifiers 1 through 4 left to right, looking from the rear of the amplifier case – see Fig.26.

For the wiring, cut the positive, negative and ground wires so that they are a neat fit to the connectors on the Power Supply board, ensuring there is sufficient slack that you can remove PCBs later if necessary.

Do not cut the speaker output wire; this goes right through to the Speaker Protector, twisted with the extra ground wire we are about to add from the power supply. Route it with the power loom to minimise the output current loop area. That also minimises distortion by reducing the coupling of these fields into the amplifier front end and input circuitry.

Connect 450mm lengths of heavy-duty green wire from the second ground screw terminal on each output from the power supply. These go to the speaker terminals, following the speaker output wiring through the Speaker Protector. These will finally be trimmed to length when you connect these to your speaker terminals.

The Speaker Protector

We are using the four-channel version of the Multi-Channel Speaker Protector (January 2022; siliconchip.au/Article/15171). However, I had some spare six-channel versions left over from the development of that project, and it seemed a terrible waste not to use them. There is no need for more than four channels, though.

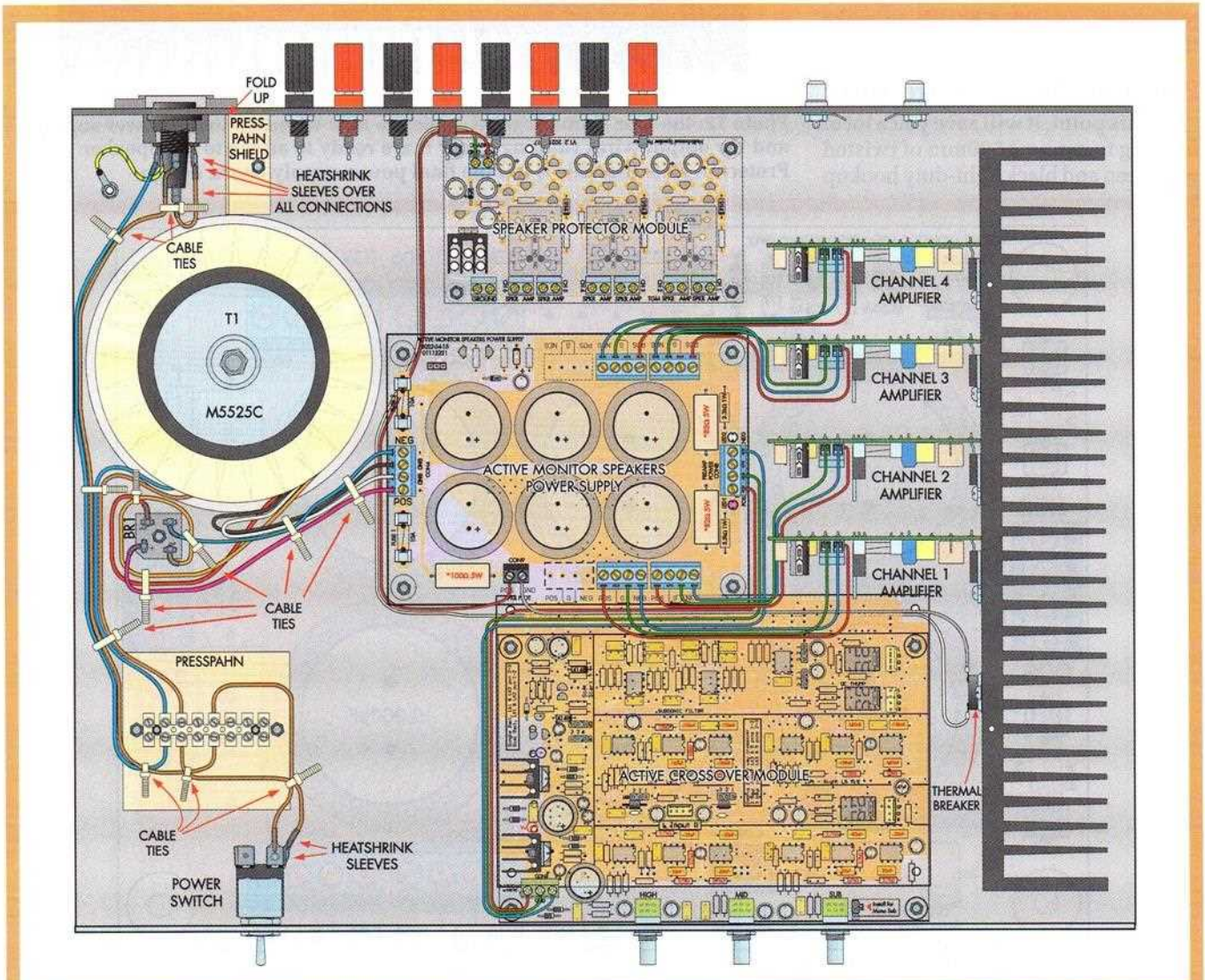

Fig.23: the mains and DC supply wiring. The signal and amplifier output wiring is shown separately, in Fig.26. Read the text for important information on safely running and insulating the mains wiring.

To test these, power them from a bench supply. As described in the original article, apply positive and negative DC voltages to the AMP inputs one by one, and check the relevant relay 'clicks' out. With this working, your speaker protection is good to go.

Mount the module to the chassis using tapped spacers and machine screws with flat and shakeproof washers. Wiring the protectors into the system is easiest with the rear panel removed. Wire up the inputs as shown in Photo 13. Note the following:

1 - The ground wire from the power supply to the speaker terminals runs straight underneath the Speaker Protector PCB.

2 - I twisted the output wires with the ground, as shown in the photo. This keeps things neat and again minimises current loops.

3 - I marked the wires to be soldered to the output terminals with a small piece of heatshrink tubing to ensure I did not confuse them with the amplifier outputs, then connected these to the "SPKR" terminals. I ran channels 1-4 left-to-right across the protector – although the critical thing to get right is the pairing of the amplifier and speaker terminals.

4 - These connections are definitely the fiddliest bit of this project. Use needle-nosed pliers, and don't cut the leads too short.

Now cut a 600mm of white light-duty hookup wire plus two 300mm lengths (white & red) for the speaker protector power and ground connections. Twist them together and secure with heatshrink tubing, referring to Fig.23 for the required layout. Run the wires between the Speaker Protector power terminal, under the Power Supply PCB to the power output for the Speaker Protector, with the GND side going via the thermal switch.

The connections to the thermal switch are made using 6.3mm spade lugs.

The recommended 100Ω 5W resistor on the Power Supply PCB is the correct value for a 25V AC transformer. If your transformer voltage is below 20V AC or above 30V AC, check this resistor once it is operational and adjust as needed. Top tip: connect this wire before you screw the rear panel on unless you have three arms!

Transformer and rectifier

Now is the time to install the transformer. The recommended transformer is a 25+25V AC 300VA toroidal type. A lower power unit would work but should only be used if you will either reduce the supply voltage or don't plan on ever driving the amplifier hard.

Suppose you really want more than 50W output per driver and will only ever connect this to 8Ω speakers or our Active Monitor Speakers.

In that case, you could use a 30V AC transformer instead, provided you check the voltage ratings of all the power supply capacitors. That will give you close to 70W per output.

I have specified a 35A bridge rectifier; this is especially necessary if you use high-value capacitors on the Power Supply board. The 35A bridge rectifier should be mounted to the base of the chassis with a 25mm-long M3 panhead machine screw with a flat washer and shakeproof washer. Put a dab of thermal paste under the bridge rectifier to ensure it stays cool even if the amp is driven hard for extended periods.

Secure the power transformer with the flying leads toward the bridge rectifier. We are trying to minimise high current paths near the crossover here. Transformers are typically supplied with two rubber washers for the top and bottom, plus an M6 bolt and dished plate. Do the bolt up moderately tight, but not so tight that you crush the windings.

Using the colour codes for the Altronics transformer:

1 - Connect the white and black secondary wires directly to the middle two GND terminals on the power supply PCB. If necessary, scrape the enamel insulation off to expose bare copper. Also check that the tinning on these wires does not extend back under the PVC sleeve, as that can be a shorting hazard.

2 - Next, connect the orange and red wires to the AC terminals on the bridge rectifier. Usually, the positive terminal and one AC terminal are marked on rectifiers. The other AC terminal will be diagonally opposite the marked one, and the negative terminal will be diagonally opposite the positive terminal.

3 - You will need to cut these leads to a sensible length, but too long is better than too short. These wires have very high current pulses, and we don't want big loops to generate magnetic fields. Depending on the type of wire used, you might need to scrape off the enamel coating after cutting them.

4 - Tie wrap the leads from the Power Supply as shown in the photos.

It's now time to install an eight terminal length of the terminal strip. These come in various sizes; 57mm spacing is good for the recommended part. If you are using an alternative, check the mounting hole placement. Cut a 70 × 80mm piece of insulating card such as Presspahn and fit it under the terminal strip. Our terminal strip is laid out as shown in Fig.23.

Photo 13: the wiring to the Speaker Protector is easier to do before you have fully mounted it in the chassis. Note the removal of the rear panel to gain some extra space while doing this.

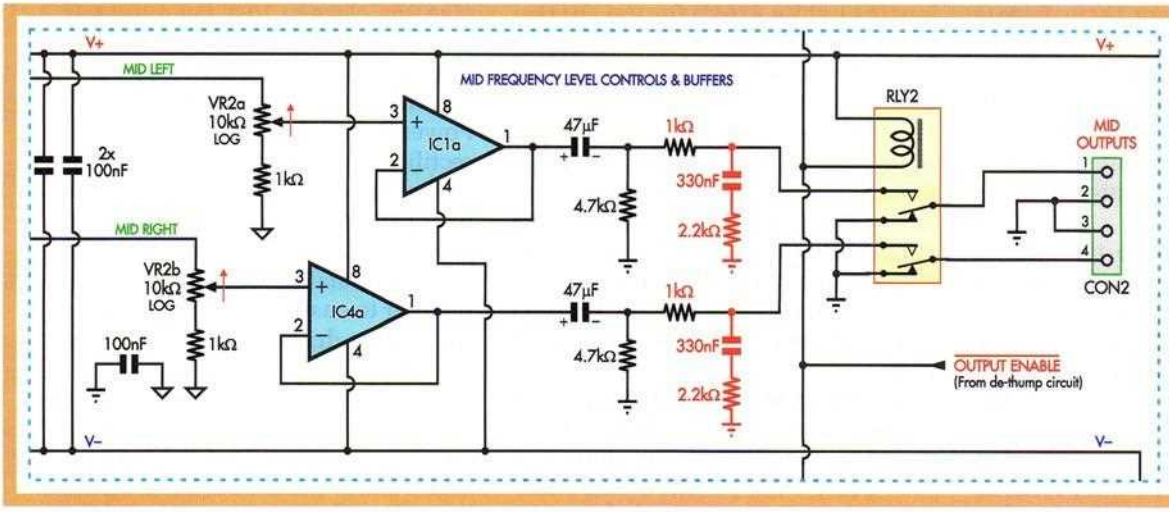

Fig.24: these minor modifications to the Active Crossover midrange/ woofer output implement 'baffle step correction' below 250Hz. The 2.2kΩ resistors and 330nF capacitors are added to the existing PCB, while the existing 100Ω resistors change to 1kΩ.

Now do the mains wiring as follows, using Fig.23 as a guide:

1 - Attach the IEC socket to the case using 10mm M3 panhead screws, nuts and shakeproof washers. The nuts need to make connection to the chassis by scraping away any paint or anodising. Connect the IEC Active pin through the fuse to the terminal strip using brown mains-rated wire.

2 - Connect the active from the terminal strip through the power switch and back to the terminal strip (making the front panel easy to remove). Ensure that the active input wire goes to the power switch's switched (NO) pin, with the output from the common terminal (so the spare pin is not connected to Active when power is off). Insulate the pins on the switch, including any unused ones.

3 - Connect the Active wire from the front panel switch to one side of the transformer primary.

4 - Connect a wire to the IEC Neutral pin running alongside the Active run to the front panel, then to the terminal strip using blue mains-rated wire.

5 - From here, connect to the other side of the transformer primary.

6 - Connect the Earth pin of the IEC connector to the chassis Earth lug using a 3.2-4mm solder lug or (even better) crimp eye terminal screwed down securely to an M3 machine screw to the chassis. Make sure that the paint on the chassis is scraped back to bare metal and that you have a star washer to cut through to the chassis under the bolt. Use green/yellow striped wire for this.

7 - Score and fold the 120 x 40mm sheet of Presspahn to form an L-shape 90mm tall, 30mm wide and 40mm deep. Mount it between the mains input and speaker terminals using a 10mm machine screw, flat washer, shakeproof washer and nut as shown in Figs.23 & 26, just touching the bottom of the lid.

Active Crossover

When building the Active Crossover, install Altronics H0655 heatsinks (or equivalent) in place of the suggested Altronics H0650. These are twice the size and will keep the regulators cool during operation.

Compensation for baffle diffraction requires a slight boost to the bass/mid output below about 250Hz. This compensates for diffraction from the edges of the loudspeaker for the particular enclosure. The following changes suit the Active Monitor Speakers; for others, you will need to change the values:

1 - Instead of 100Ω at the output of the midrange/bass section, use 1kΩ (these are next to RLY2).

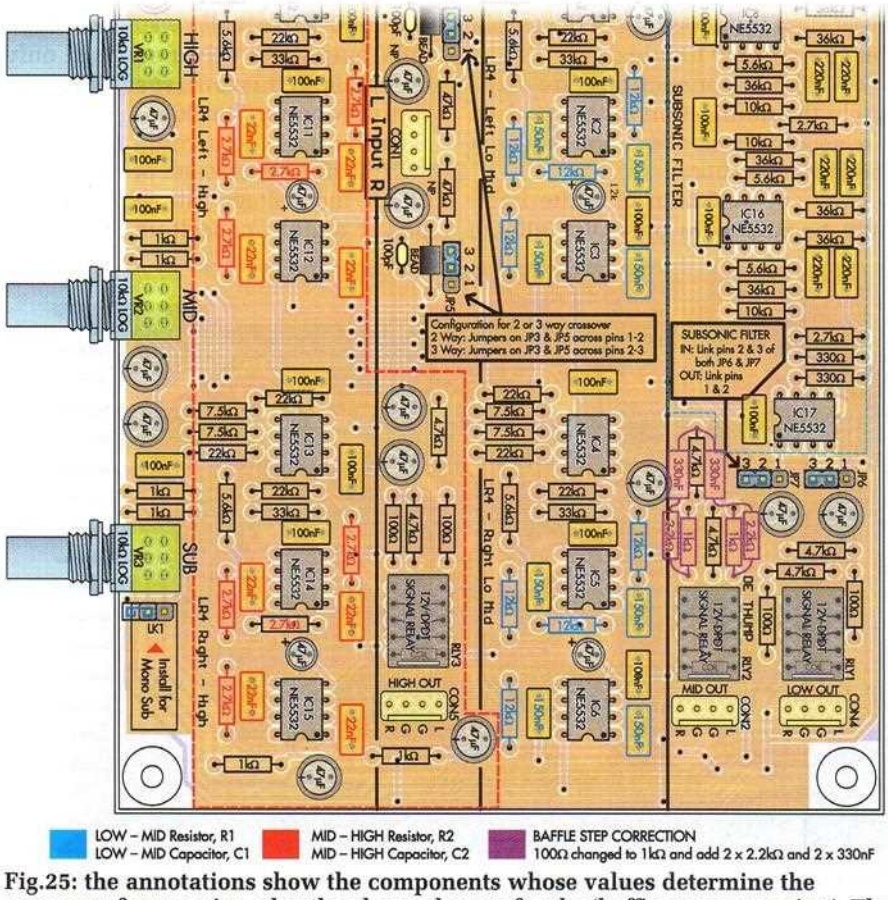
HIGH
MID
SUB
L Input R
LR4 Left - High
LR4 Left - Lo Mid
LR4 Right - High
LR4 Right - Lo Mid
SUBSONIC FILTER
Configuration for 2 or 3 way crossover
2 Way: Jumpers on JP3 & JP5 across pins 1-2
3 Way: Jumpers on JP3 & JP5 across pins 2-3
SUBSONIC FILTER
IN: Link pins 2 & 3 of both JP6 & JP7
OUT: Link pins 1 & 2
Install for Mono Sub
HIGH OUT
MID OUT
LOW OUT
LOW – MID Resistor, R1
LOW – MID Capacitor, C1
MID – HIGH Resistor, R2
MID – HIGH Capacitor, C2
BAFFLE STEP CORRECTION
100Ω changed to 1kΩ and add 2 x 2.2kΩ and 2 x 330nF

Fig.25: the annotations show the components whose values determine the crossover frequencies, plus the changed parts for the 'baffle step correction'. The full overlay for the Active Crossover PCB is shown in the October 2021 issue.

2 - Connect a 2.2kΩ resistor in series with a 330nF MKT capacitor and connect this network from the junction of the 1kΩ resistor & relay to ground.

The modified Active Crossover circuit is shown in Fig.24, while PCB changes are shown in Fig.25.

Also, when building the Active Crossover, set it up for dual rail operation and set the jumpers as described in the original article. It's a good idea to do a quick bench test to check its operation after construction. Feeding it with ±15V DC will allow you to check that the regulators are generating the correct output voltages, and that the de-thump relays click out after a couple of seconds.

The jumpers on the Active Crossover need to be set as follows:

- Three-way operation is achieved with JP3 and JP5 set to pins 2-3.
- JP1 and JP2 set to pins 1-2 for dual-rail operation.
- I left the 20Hz subsonic filter in, but note that the active subwoofer will generate useful output below that! To do this, set JP6 and JP7 set to pins 2-3.

Other choices you need to make when building the Active Crossover are whether it should be a two-way or three-way crossover and what the crossover frequencies should be.

We will configure it as a three-way crossover (with the lowest output for the subwoofer) and crossover frequencies of 88Hz for Low-Mid and 2.7kHz for Mid-High. However, if you are not planning on using the system with a subwoofer, you will need to change it to a two-way crossover at 2.7kHz.

The required component values were given in Table 1 on page 48 of the October 2021 issue. They are 12kΩ/150nF for 88Hz (Low-Mid) and 2.7kΩ/22nF for 2.7kHz (Mid-High). MKT capacitors are readily available in both values in either 5% tolerance (preferable) or 10%. Use 1% metal film resistors for the best precision. The locations for all these components are also shown in Fig.25.

Now install the Active Crossover in the case. The front panel should have been drilled to suit it already. Power wiring for the Crossover should have been connected to the power supply already; route and trim this to connect to the power connector at the right front corner of the Active Crossover.

Doing the input and output wiring for the Active Crossover involves

Parts List – Active Monitor Amplifier / Crossover

1 430mm wide, 330mm deep 2RU black rack-mount case **[Altronics H5038]**
4 assembled Hummingbird amplifier modules (Silicon Chip, December 2021)
1 assembled 4-way Speaker Protector with larger heatsink (see text) (January 2022)
1 assembled Stereo Active Crossover with modifications as per text (October 2021)
1 300mm wide, 75mm tall diecast aluminium heatsink, 10mm fin spacing, 0.37°C/W **[Altronics H0545 or two Jaycar HH8555 joined with hole position adjustments]**
1 300VA 25-0-25 toroidal mains transformer **[Altronics M5525C]**
1 double-sided PCB coded 01112221, 146.5 × 108.5mm
1 250V 3A+ SPST power switch (toggle, rocker etc)
1 normally-closed thermal switch/breaker, 250V AC 10A, 70°C **[Jaycar ST3823]**
8 TO-3P insulating kits **[Altronics H7220]**
4 TO-126 insulating kits **[Altronics H7120]**
1 small tube of thermal paste
1 3.2-4mm solder lug or crimp eyelet connector

Connectors & fuses
1 chassis-mounting IEC mains input socket **[Altronics P8320B]**
4 chassis-mounting dual red/black binding posts **[Altronics P9257A]**
1 red chassis-mounting insulated gold RCA socket **[Altronics P0218]**
1 black chassis-mounting insulated gold RCA socket **[Altronics P0220]**
2 yellow chassis-mounting insulated gold RCA sockets **[Altronics P0219]**
1 8-way 17.5A terminal block strip **[Altronics P2135A]**
6 4-way 5mm terminal blocks (CON1-2, 4, 6-8) **[Altronics P2026A]**
1 2-way 5mm terminal block (CON9) **[Altronics P2034A]**
4 2-way polarised header plugs with pins **[Altronics P5472 × 4 + P5470A × 8]**
1 M205 10A chassis-mount safety fuse holder **[Altronics S5992 or Jaycar SZ2028]**
1 M205 5A fast-blow fuse
4 M205 PCB-mount fuse clips
2 M205 250V 10A ceramic fuses

Hardware
1 M3 × 25mm .... 9 M3 × 16mm ..... 9 M3 × 10mm ..... 19 M3 × 6mm panhead screws
35 M3 shakeproof washers
32 M3 flat washers
7 M3 hex nuts
8 M3 × 10mm tapped spacers
40 100mm cable ties
2 sheets of Presspahn or similar insulating material, 80mm × 70mm & 120 × 40mm sheets

Wire & cable
1 2m length of each colour **(red, black, green & white)** heavy-duty (10A+) hookup wire
1 2m length of 7.5A mains-rated brown wire
1 1m length of 7.5A mains-rated blue wire
1 10cm length of 7.5A mains-rated green/yellow striped wire
1 150cm length of each colour **(green & white)** light-duty hookup wire
1 50cm length of red light-duty hookup wire
1 3m length of figure-8 screened cable **[Altronics W2995 or W3022]**
1 10cm length of each diameter **(3mm, 5mm & 10mm)** heatshrink tubing

Semiconductors
1 BC556 80V 100mA PNP transistor (Q1)
1 BD139 80V 1A NPN transistor (Q2)
1 BC546 80V 100mA NPN transistor (Q3)
2 5mm LEDs, any colour (LED1, LED2)
1 12V 400mW zener diode (ZD1) **[eg, 1N963]**
1 400V+ 35A chassis-mount bridge rectifier with spade terminals (BR1)
1 1N4148 75V 200mA signal diode (D1)

Capacitors
6 10,000µF 50V electrolytic, 10mm lead spacing (6800µF-15,000µF acceptable)
1 47µF 50V low-ESR radial electrolytic
2 330nF 63V MKT 1 •

Resistors *(all 5% 5W wirewound unless otherwise stated)*

3 22kΩ 1% 0.6W metal film	2 3.3kΩ 1W	2 2.2kΩ 1% ¼W metal film •
2 1kΩ 1% ¼W metal film •	1 100Ω	2 82Ω

• *for the baffle step correction (see Fig.25)*

making four flying leads of 800mm length using figure-8 shielded cable, plus two at 350mm long. To make the cables, you need the following parts (also in the parts lists):

- 4 × four-way 2.54mm polarised header plugs with matching pins
- 4 × two-way 2.54mm polarised header plug with matching pins
- 2 × 80cm lengths and 2 × 35cm lengths of figure-8 screened cable
- 3mm and 5mm heatshrink tubing

Photo 14 shows what the header ends of these cables should look like. To make them:

1 - Start by separating the two coax channels, then strip 25mm of the outer sheath from each, exposing the braid.

2 - Tease the inner conductor from the braid and strip the end by 5mm.

3 - Twist the braids together into a neat bundle.

4 - Cut two 20mm lengths of 3mm heatshrink, such that when put on the braid, it will leave enough exposed copper to crimp to.

5 - Slide a 10mm-long, 5mm diameter piece of heatshrink over both the braid and central conductor but do not shrink it yet.

6 - Slide the 3mm heatshrink over the braid; there should be 4-5mm of wire protruding. Shrink this down.

7 - Slide the 5mm heatshrink to cover about 3mm of the junction where the braid and inner core separate and shrink it down.

8 - Present the braid to the crimp connector. You need to trim off excess braid wire so that the strain relief crimp will go over it, and there is about 3mm of braid wire in the electrical crimp section.

9 - Take one of the pins and, using sharp-nosed pliers, crimp the end of the braid conductor. Carefully add a tiny amount of solder to the crimped part, careful not to let it wick down to the spring section.

10 - Strip back 3mm from each of the inner conductors and crimp and solder as above. I was dissatisfied with the strain relief crimp missing the plastic and added a small piece of heatshrink, but that is optional.

11 - Now push the pins into the header plug, with the braids in the middle and left and right conductors on the outside. You will feel and/or hear a click when they seat properly.

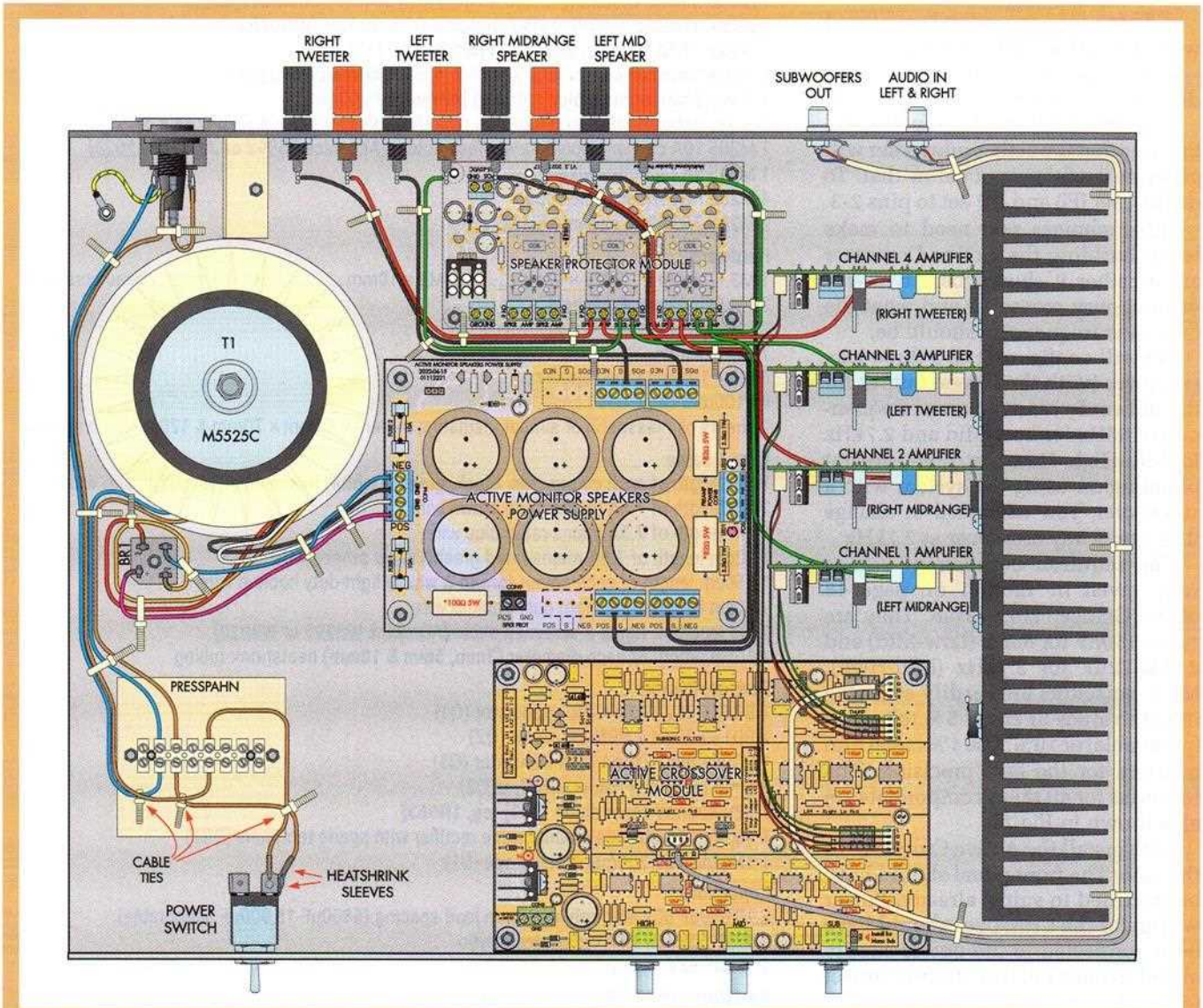

Fig.26: the signal wiring for the Active Monitor Speakers. While the wires from the Active Crossover board to the Hummingbird amplifier modules are shown separately for clarity, they should be run using figure-8 shielded cable to avoid hum and buzz pickup.

Now that you've made the cables, you can complete the signal wiring as in Fig.26. The input and subwoofer output connections go to the rear panel, while the midrange/woofer and tweeter outputs go to the amplifier modules. I opted to use modules 1 and 2 (the two most forward in our case) for the midrange/woofer and modules 3 and 4 (rearmost) for the tweeters. The final configuration is shown in Photo 15.

Testing

By this stage, you should have verified that the amplifier modules, Speaker Protector and Active Crossover function correctly. The next steps are a few safety checks:

1 - Using a DMM, check that there is no continuity between the chassis and the power supply ground (or, for that matter, the main positive and negative DC rails). The aim here is to check the integrity of the insulation bushes. If your meter registers a resistance on its 20MΩ range, you need to find and fix the conductive path.

2 - Using a DMM, check that there is a solid connection between the Earth pin of the mains socket and all chassis panels. You should get a reading under 1Ω in each case. If not, find the problem and, if necessary, add Earth jumpers from the affected panels to the base panel or main Earth lug.

3 - Using a DMM, check that there is no continuity from the Active/ Neutral wiring to the amplifier's chassis and the power supply 0V point. If your meter registers a resistance on the 20MΩ range, you need to find and fix the conductive path.

Assuming that all checks out, insert the 5A mains fuse in the chassis holder and, while monitoring the voltage across the main supply rails, briefly switch on mains power. As you need to do this with the lid open, ensure you stay clear of the mains wiring while it's switched on. Use two DMMs with alligator clip leads attached so you can do it hands-off.

If you don't have two DMMs or enough clip leads, connect a DVM between the main positive and negative rails.

The rails should very quickly rise to close to ±35V or 70V total. They could be a few volts higher or lower than that. If you don't get the correct reading(s), switch off quickly and check the following:

- Carefully check all of the mains wiring.
- If the voltage is zero: is the fuse blown? Is the switch on?
- Is there mains voltage across the transformer primary? You can check this by probing the terminal strip.
- Is there AC at the input to the bridge rectifier?
- Is there pulsating DC at the power supply input terminals?

The voltage across each pair of amplifier module outputs should be under ±50mV.

If that all checks out, apply an AC signal (or music) to the inputs and check that the sub, midrange/woofer and tweeter outputs behave as expected. If not:

- Check the wiring from the Active Crossover to the amplifier modules.
- Check that the amplifier modules have a reasonable output; this can be measured on the top of the emitter resistor using an oscilloscope probe or AC voltmeter.
- Check that the amplifier outputs go to the correct Speaker Protector terminals and, subsequently, the rear panel connector.
- Check that the Speaker Protector is working properly.

At this point, you should have a functioning Active Crossover Amplifier. The levels need to be set to match your speakers. The process for doing that was at the end of the article on the Active Monitor Speakers published last month, so refer back to that. If you're using the Active Crossover Amplifier with different speakers, you'll have to tweak the crossover frequencies and levels to suit.

Next month

The final article in this series will describe the High-Performance Subwoofer that can optionally be paired with the Active Crossover Speakers. It connects to the subwoofer output on the Active Crossover Amplifier and extends the bass of the system almost down to 20Hz.

We highly recommend that this Subwoofer be built as part of the system, although you can still enjoy the Active Monitor Speakers without it. SC

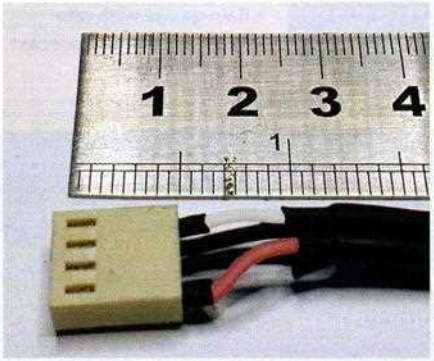

Photo 14: this is how each of the four stereo shielded cables should look once terminated to the polarised plugs, ready to connect to the Active Crossover board.

Photo 15: a close-up shot showing the details of the complete low-voltage DC and signal wiring.

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	XC0366	XC0412	XC0400	XC0442	XC0432	XC0434	XC0440
Touchscreen						√	
Indoor Thermometer	√	√	√	√	√	√	√
Outdoor Thermometer	√	√	√	√	√	√	√
Min/Max Records	√	√	√	√	√	√	√
Hygrometer	√	√	√	√	√	√	√
Wind Speed			√		√	√	√
Wind Direction			√		√	√	√
Wind Chill			√		√		√
Dew Point			√		√	√	√
Rain Gauge			√		√	√	√
Rain Rate			√		√	√	√
Barometric Pressure	√	√	√	√	√	√	√
Moon Phase	√	√			√	√	√
Time/Date Display	√	√	√	√	√	√	√
High/Low Alarms	√	√	√	√	√	√	√
Transmitter Power	2 x AAA	2 x AA	2 x AA	2 x AA	3 x AA	3 x AA	7 x AA
Colour Screen				√		√	√
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NORDIC SEMICONDUCTOR nRF5340 DK

Review by Tim Blythman

Nordic Semiconductor is known for its wireless communications products and low-power devices; you can find their parts in many products. This board is based on the nRF5340 SoC (system on a chip), a dual-core ARM chip that can dedicate one core to wireless communications, leaving the main core free for other applications.

We decided to try out the new nRF5340 DK development board from Nordic Semiconductor since it is a bit different from anything we've reviewed previously. The suggested applications for the nRF5340 are:

- Advanced computer peripherals and I/O devices
- Health/fitness sensor and monitor devices
- Wireless payment devices
- Wireless audio devices, eg, headphones, microphones, true wireless earbuds and speakers with Bluetooth Low Energy (LE) Audio
- Smart home sensors and controllers
- Industrial IoT sensors and controllers
- Interactive entertainment devices
- Remote controls
- Gaming controllers
- Professional lighting
- Wirelessly connected luminaires

You could be using devices daily that include Nordic Semiconductor parts without realising. If you're using something that relies on Bluetooth LE communication, there's a reasonable chance it includes a chip from Nordic Semiconductor.

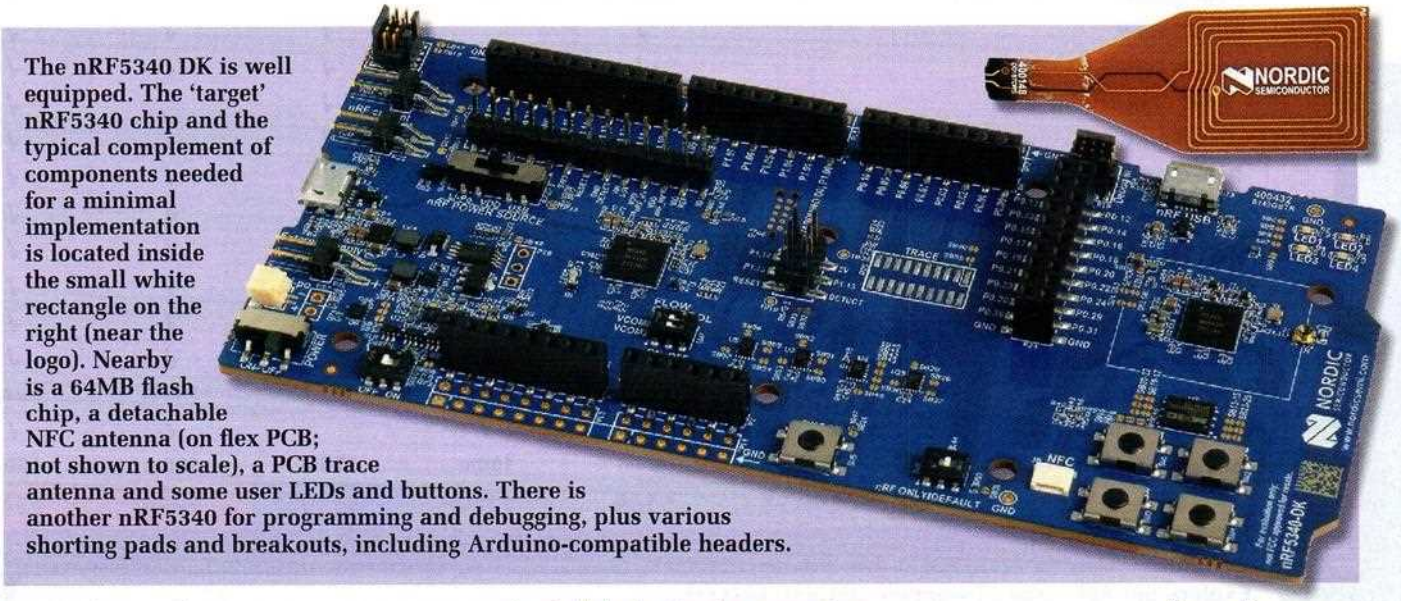
They also make products that work with other wireless protocols and bands and are known for their low power consumption.

While Nordic Semiconductor has a history going back around 40 years, chips like the nRF5340 are based on a line of parts dating to 2012: the nRF51 series is a low-power wireless SoC incorporating an ARM Cortex M0 microcontroller and a 2.4GHz RF transceiver.

The later nRF52 series used an ARM Cortex M4. These chips are even at the core of some Arduino boards, like the Arduino Nano 33 BLE and BLE Sense, which have the nRF52840. The Arduino Primo uses an nRF52832, providing Bluetooth LE and NFC via PCB antennas. The BBC micro:bit V2 uses an nRF52833.

Fig.1 shows a very small subset of the boards that can be programmed with the nRF Connect SDK, which we will discuss later.

There is also the nRF91 series,



The nRF5340 DK is well equipped. The 'target' nRF5340 chip and the typical complement of components needed for a minimal implementation is located inside the small white rectangle on the right (near the logo). Nearby is a 64MB flash chip, a detachable NFC antenna (on flex PCB; not shown to scale), a PCB trace antenna and some user LEDs and buttons. There is another nRF5340 for programming and debugging, plus various shorting pads and breakouts, including Arduino-compatible headers.

which implements LTE (a type of 4G mobile phone technology) and GPS (global positioning system). Naturally, these chips operate on different frequency bands than the nRF5 series parts.

The nRF53 family is the latest in the nRF5 series, and the nRF5340 DK is a development board for the nRF5340 chip. So it also implements 2.4GHz communication protocols such as Bluetooth and NFC.

We have previously reviewed a Nordic product in the September 2002 issue ("One-chip Transceivers"; siliconchip.au/Article/6738). The chip described in that article was the nRF401, a far simpler transceiver than the nRF5340.

The nRF5340

Unlike the earlier single-core parts, the nRF5340 is a single chip containing two distinct ARM Cortex M33 cores. The smaller 'network' processor runs at 64MHz and is provisioned with 256kiB of flash memory and 64kiB of RAM.

The network processor handles wireless communications and, typically, the wireless protocol stack. That can include Bluetooth LE, Bluetooth 5.3, LE Audio, ZigBee and the Matter standard, which all operate on the 2.4GHz ISM (industrial, scientific and medical) band.

The nRF5340 does not offer WiFi (which often uses the 2.4GHz band); to do this requires a companion IC.

The 'application' processor can run up to 128MHz and has a separate 1MB of flash memory and 512kB of RAM. Security is provided by ARM

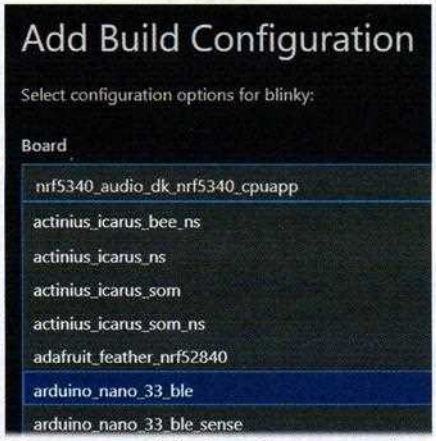


Fig.1: some of the boards supported by the nRF Connect SDK; several Arduino boards and the BBC micro:bit are included. Even if you don't have an nRF5340 DK, you might have another board that it can program.

TrustZone and CryptoCell-312 with secure storage and bootloader.

This processor can also access external programs stored in off-chip flash memory via QSPI, expanding the non-volatile storage. Onboard peripherals include full-speed USB, UART, SPI, TWI (I^2C), I^2S (for audio data) and a 12-bit, 200 kilosample/second ADC.

The application processor also implements NFC. NFC allows devices to communicate, pair and authenticate when in close proximity, typically less than 5cm (this technology is used by "payWave" with credit cards and smartphones). This can allow, for example, a Bluetooth connection to be initiated without requiring a PIN code to be entered.

The processor cores communicate via a dedicated IPC (inter-processor communication) peripheral on each core and a shared memory area.

The two cores are separate enough that it's entirely possible to use just one of them. A sample 'empty firmware' for the application core hands control of the I/O pins to the network core and places the application core into a low-power mode, allowing the network core to do all the work.

This may be suitable for designs that can make do with just the resources available on the network core. It's also possible to design for just the application core, although that would not allow wireless communication.

So it's a capable chip that would easily outperform many of the other chips that we have used in our projects previously, plus it can handle a range of wireless communication protocols.

The nRF5340 DK board

The nRF5340 DK is the official development kit from Nordic Semiconductor for the nRF5340. It's a populated PCB measuring 64mm by 136mm – see Fig.2.

The reverse side contains only a 2032 coin cell holder and is otherwise covered with information about the roles of the various shorting pads on the front of the PCB.

The nRF5340 chip is in the white rectangle on the right. This area also contains other essential components needed for its operation, such as bypass capacitors and a crystal oscillator.

A 64MB QSPI flash memory chip sits just outside this area, as does an SWF connector for making RF measurements and a PCB trace antenna for 2.4GHz communications. The

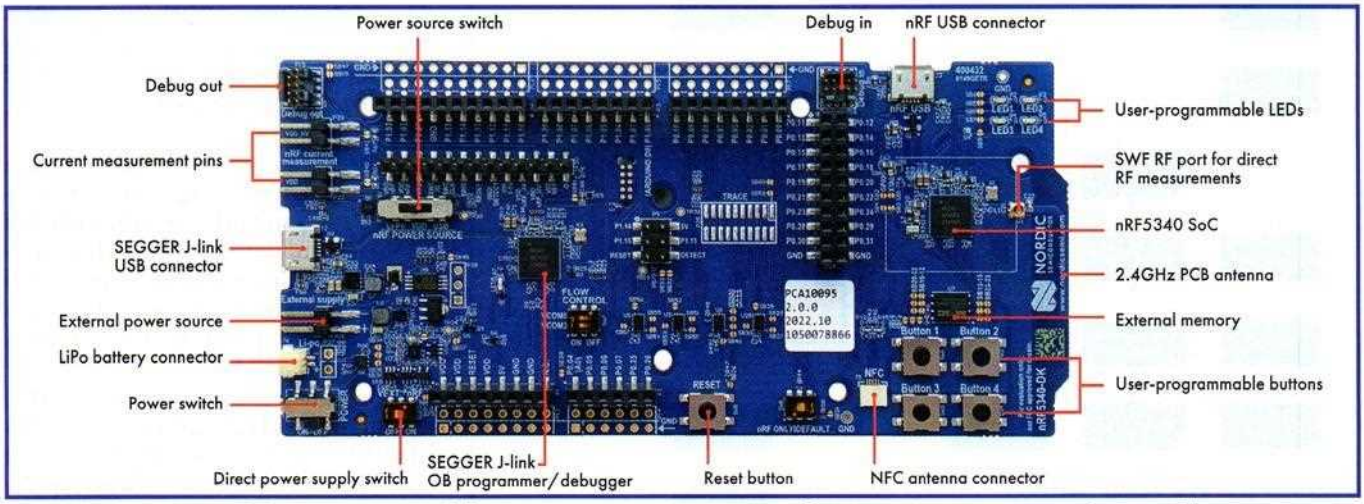


Fig.2: the features and documentation of the nRF5340 DK are pretty good. It contains many more features than most people would use; many can be disconnected by opening a shorting pad on the PCB.

antenna should also be considered an essential component for RF applications. A second micro-B USB socket connects to the USB pins on the nRF5340, allowing USB applications to be tested.

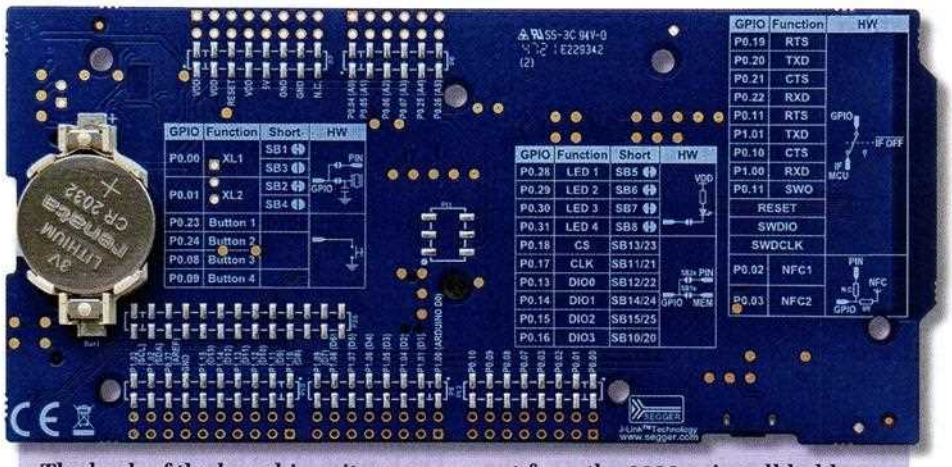
The general purpose I/O (GPIO) pins are broken out to headers and edge connectors, including a set of Arduino R3-compatible headers. This means you can use that you can use common shields and modules for prototyping.

There is a connector for an included NFC antenna for NFC testing. Four tactile switches and four LEDs are also provided for user interfacing.

The remainder of the kit contains a second nRF5340 chip programmed as a SEGGER J-Link Debugger, which provides a virtual mass storage device so you can program the target nRF5340 via a simple drag-and-drop interface. The Debugger chip also provides USB virtual serial ports for communication with the target nRF5340 using its UART peripherals.

As well as USB power, a switch allows the nRF5340 to be powered from the 2032 coin cell or a lithium battery connected to a dedicated connector. The Debugger and target nRF5340 can be independently powered if required.

There are shorting pads that can be opened to allow the placement of shunt resistors for current measuring.



The back of the board is quite sparse; apart from the 2032 coin cell holder, the PCB silkscreen lists the roles of the various sorting pads.

External headers are provided for making measurements across the shunt resistors.

Numerous other shorting pads can be used to disconnect features on the nRF5340 DK, to allow the pins to be used for other purposes.

A small slide switch is provided near the buttons that control several analog switches. This disconnects the debugger chip so accurate current measurements can be made with just the target nRF5340 chip powered.

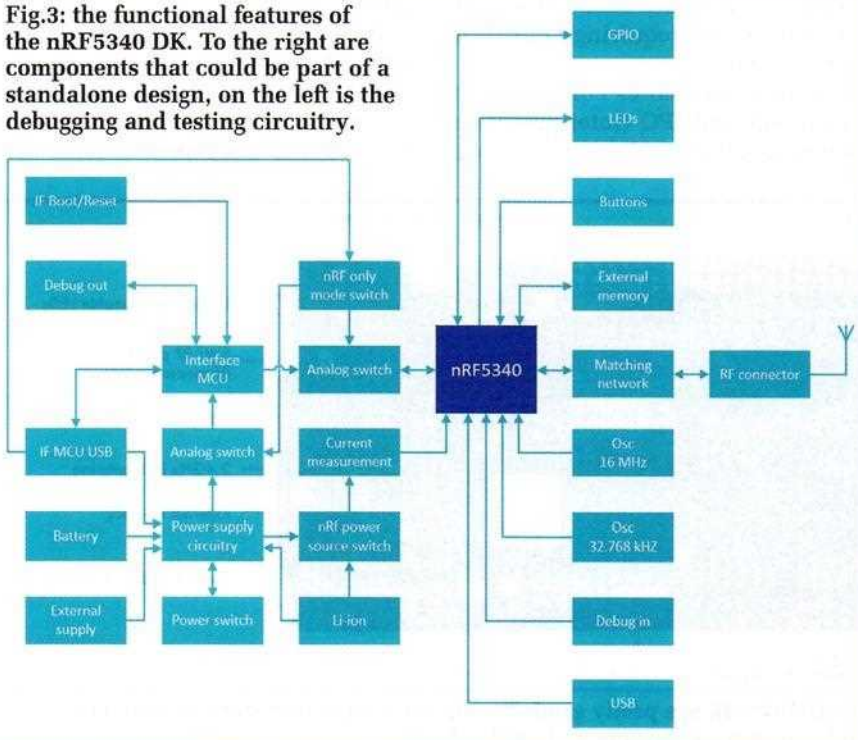
This is especially important at the low power levels that the nRF5340 DK is capable of. As you can see, the nRF5340 DK is not just a simple breakout board, but a fully-fledged nRF5340 implementation accompanied by programming, debugging and testing features.

Such an arrangement should allow developers to get their software well advanced and their hardware prototypes very close to complete before needing to step beyond the nRF5340 DK.

The full schematic and Altium Designer PCB files are also available for download, easing the design of custom hardware and helping developers see precisely how the development kit board is configured.

Fig.3 shows a block diagram of functional parts on the nRF5340 DK. The user guide at siliconchip.au/link/abgy goes into more detail about the various board features and important details like pin allocations.

Fig.3: the functional features of the nRF5340 DK. To the right are components that could be part of a standalone design, on the left is the debugging and testing circuitry.



nRF Connect SDK

Such a development board is not of much use without an appropriate SDK (software development kit). The nRF Connect SDK is what Nordic Semiconductor provides for the nRF52, nRF53 and nRF91 series of devices. It can run under Windows, Mac and Linux.

It uses Microsoft's Visual Studio Code as its IDE (integrated development environment). The SDK includes protocol and hardware libraries, samples and demo code. Once a project is set up, a single mouse click can compile code and program it to the chip on the nRF5340 DK.

There are a few steps to set the IDE up, but it is all fairly intuitive. A video playlist explains the setup process and then shows how to create a basic application using example code, compile it and run it on the nRF5340 DK.

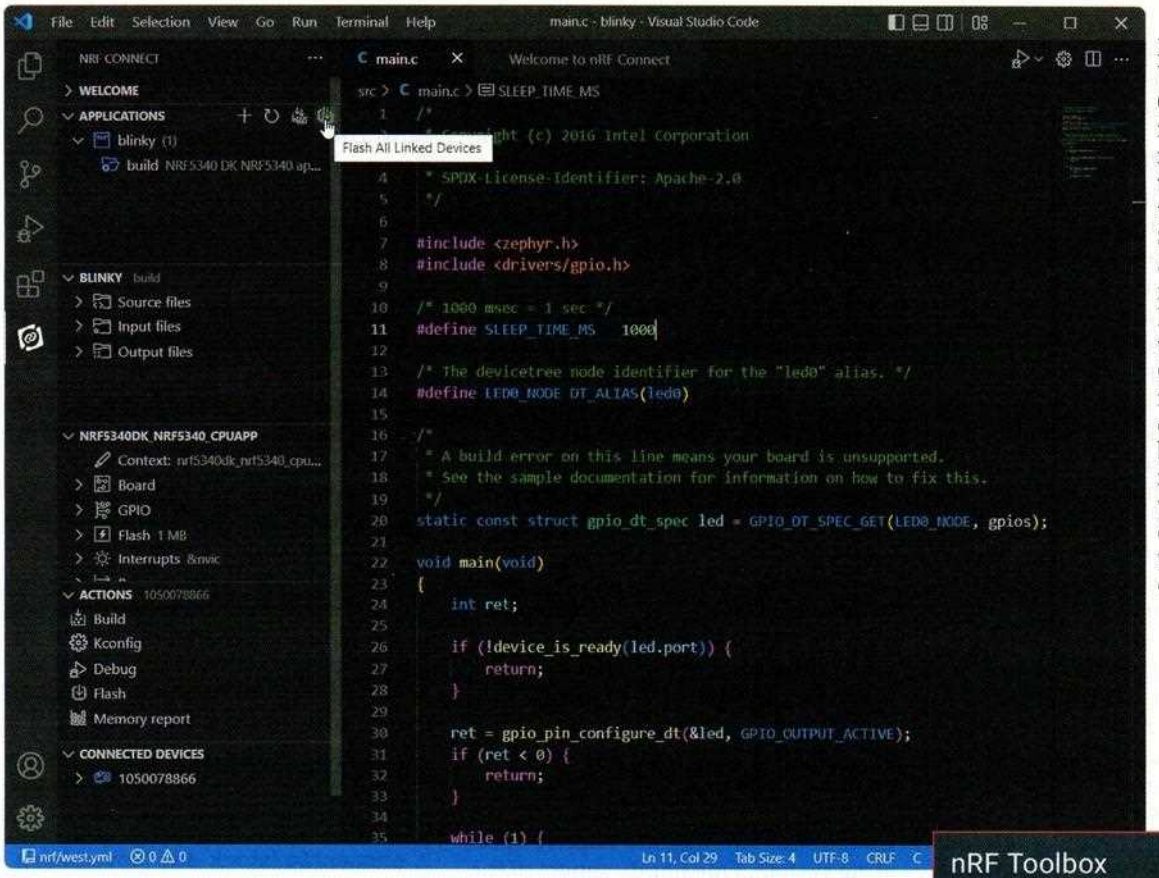


Fig.4: inside Visual Studio Code, code editing is done in the main window on the right, while the nRF Connect SDK provides actions and resources at the left to work with the nRF5340 DK. Once everything is set up, a single click on the button under the mouse pointer will compile the code and program the selected device.

That YouTube playlist can be found at siliconchip.au/link/abgz or search YouTube for "nRF Connect for VS Code tutorials". There is also a text version at siliconchip.au/link/abh0

There were slight differences in the steps required for the versions shown in the tutorials and the latest versions of the software, but it was easy enough to figure out. There are a few steps using the nRF Connect for Desktop program to install the 'toolchain' (compiler and programmer software) and Visual Studio Code.

A separate Programmer utility can also be installed, which allowed us to use some sample HEX files that we found mentioned in another tutorial. These and other tools can be installed from nRF Connect for Desktop.

On our Windows machine, it came to around 4GB installed, including ~3.5GB for the nRF software and ~0.5GB for the Visual Studio Code IDE.

After setting up the first sample project, you'll see a window much like Fig.4. The code for main.c is in the large window on the right, while the panels give a range of information. Compiling and programming the project takes only a single click on the button under the mouse pointer.

The sample software for the nRF5340 chip is based on the Zephyr RTOS (real-time operating system), which has support for different chips, including many based on the ARM architecture.

Similar to an operating system on a PC, Zephyr RTOS provides a wide range of interfaces and features uniformly on differing hardware. That makes it easy to get the same software running on various devices.

Zephyr is optimised for use on smaller devices such as microcontrollers, and there are many libraries provided that offer simple interfaces to the peripherals.

nRF Toolbox app

The nRF Toolbox app is available for Android and iOS devices. It's designed to interface with sample applications (from the nRF Connect SDK) that use Bluetooth LE. So it's pretty easy to check for Bluetooth functionality.

You can download the Heart Rate Monitor demo from siliconchip.au/link/abh1

It includes a pair of HEX files that can be programmed to the nRF5340 DK using the nRF Connect Programmer tool.

This then communicates with the nRF Toolbox app to form an emulated heart rate monitoring device. Fig.5

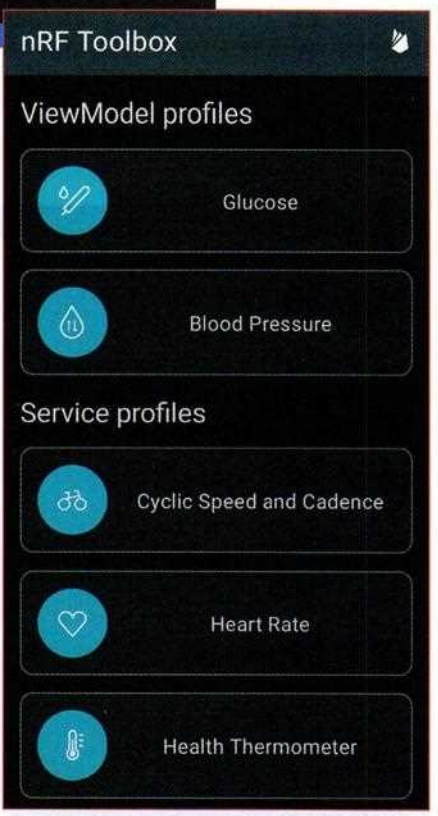


Fig.5: the nRF Toolbox app can interface with sample smartphone apps to test features like Bluetooth communication. The suggested uses of the nRF5340 include devices for health monitoring, audio playback/recording and sensing, all of which would often communicate with a mobile device.

shows the app's main screen; it's clear that health and fitness sensors are one of the intended uses of the nRF5340.

Testing the sample code

We tried a few of the code samples. The nRF Connect add-on in Visual Studio Code makes it easy to clone the examples so we could tinker with the code to see what we could change.

There are over 500 examples, including over 100 for different sensor ICs, modules and shields. Not all the examples will work with the nRF5340, but most of the ones we tried did.

Complex peripherals such as USB have examples for HID (human interface device, such as mouse and keyboard), CDC (communication device class, for virtual serial ports) and mass storage devices.

There are even more diverse examples for Bluetooth and other wireless protocols such as ZigBee. The code is all in the C language. We didn't have many surprises, and mostly, things worked as expected.

There are several NFC examples that work with a separate NFC add-on module and not with the nRF5340's inbuilt NFC peripheral, so it was simply a case of making sure that we used the correct example.

Fig.6 shows an NFC example that worked for us. It emulates an NFC tag that can be read, for example, by an NFC reader app on a mobile phone. The information shown here is displayed in Visual Studio Code, although it is also available on an external browser via the link at the bottom.

There are even audio examples available, including Bluetooth audio sources and sinks and USB examples that emulate microphones and headphones. Emulation is necessary because the nRF5340 DK does not have external audio interfaces (although they could be added easily enough).

If you are interested in audio applications, there is an nRF5340 Audio DK development kit with an onboard codec chip and a pair of 3.5mm audio jacks for handling real-life audio.

In general, we found the trickiest part of creating custom code based on the examples was finding out how to access and control the various peripherals through the Zephyr operating system. One handy aspect of the examples is that they provide liberal debugging data that you can access through one of the virtual serial ports at 115,200 baud.

Conclusion

The nRF5340-DK has been designed well and is based on the versatile and powerful nRF5340 chip. It is well backed by software that's easy to set up and use, with many examples. The design files are available, so a compatible hardware design can be developed without hassles.

While it is clearly intended to be used to develop standalone products for the nRF5340, it would also be a worthwhile starting point for those who want to experiment with Bluetooth, NFC and other wireless communications.

It would be a great way to produce a one-off project, the type that many of our hobbyist readers might consider, especially if it requires Bluetooth or other 2.4GHz wireless communications.

The nRF5340-DK can be purchased from these retailers:

1. **Mouser (in stock at time of writing):** au.mouser.com/ProductDetail/949-NRF5340-DK
2. **element14 (stock due November):** au.element14.com/3617670
3. **Digi-Key (in stock currently):** www.digikey.com.au/en/products/detail/NRF5340-DK/13544603 SC

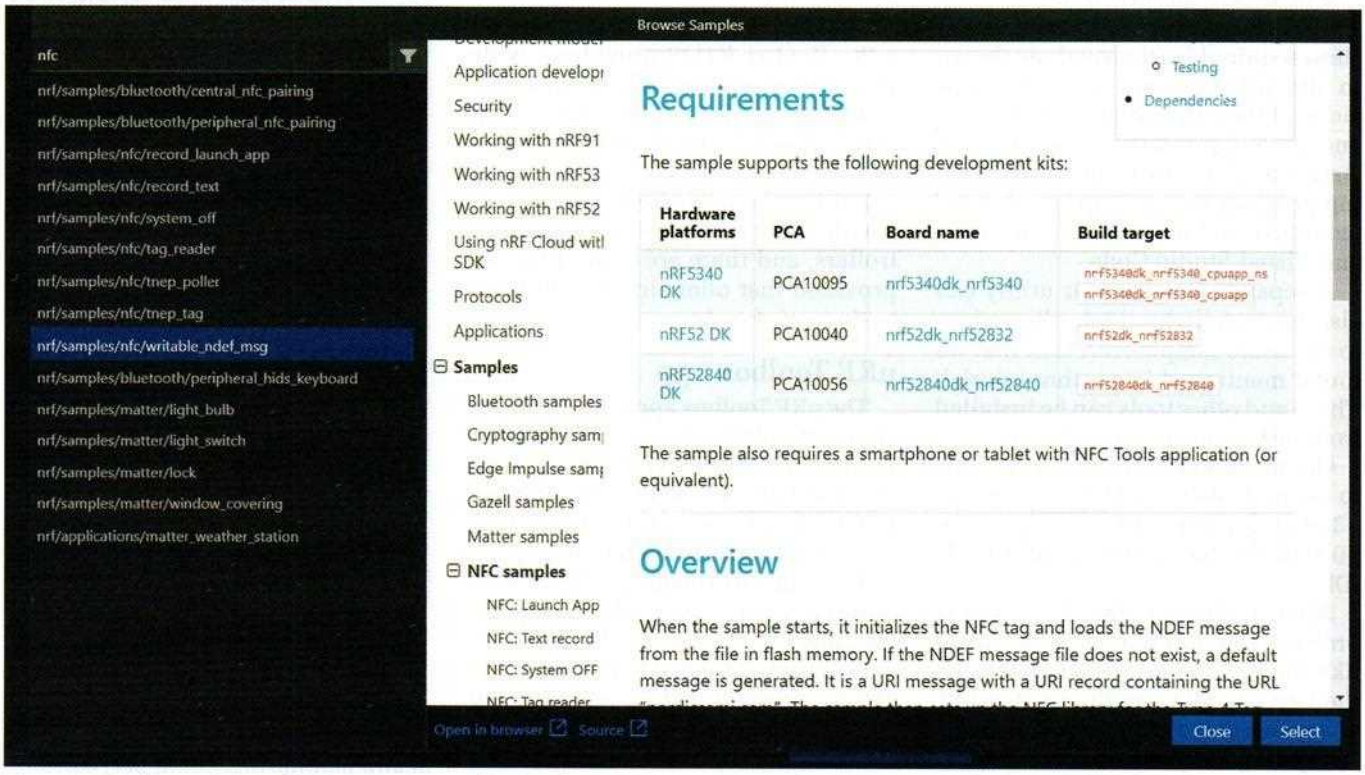
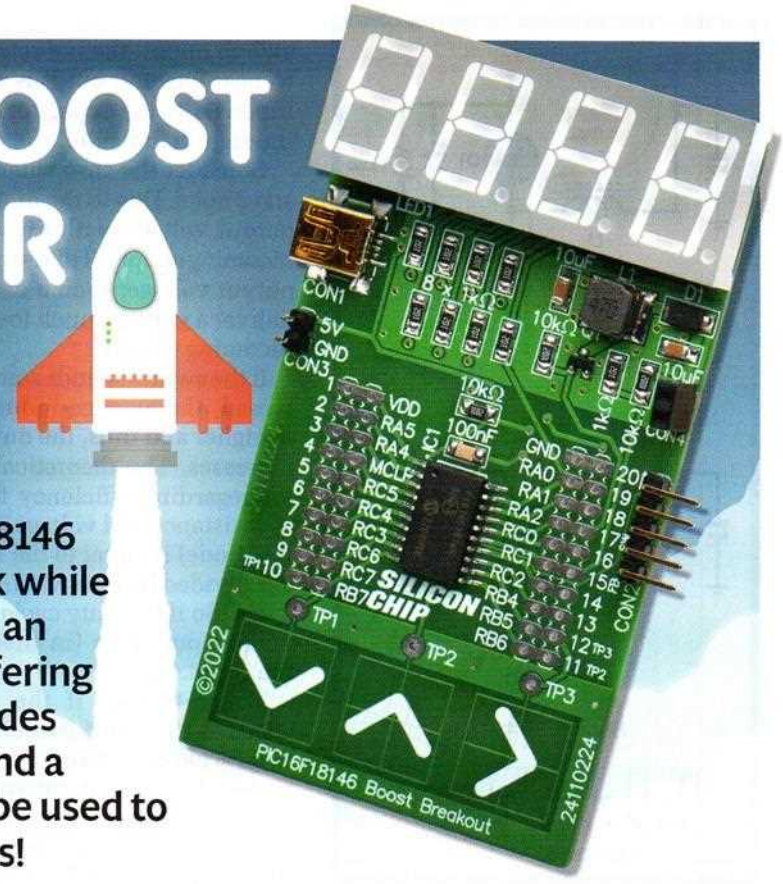


Fig.6: NFC allows data to be communicated over short ranges, often to facilitate Bluetooth pairing. In the sample software shown here, the nRF5340 DK is programmed to emulate a tag carrying data that can be scanned by a device with an NFC reader, such as a smartphone.

Digital Boost Regulator

By Tim Blythman



This board lets you use a PIC18F18146 8-bit microcontroller for any task while its onboard peripherals generate an adjustable voltage without interfering with what it's doing. It even includes some capacitive sense buttons and a seven-segment display that can be used to show the voltage or for other uses!

The PIC16F18146 micro has some interesting onboard peripherals. We realised it is possible to combine several of them with a small number of external parts to make a free-running, programmable boost voltage regulator that doesn't require any processor intervention while running.

This small PCB allows you to experiment with or use this concept. Since this 8-bit microcontroller has 20 pins, we've connected them all to headers for making off-board connections.

This design was prompted by our review of the latest 8-bit PICs in the October 2022 issue (siliconchip.au/Article/15505).

We've added a small LED display and some touch-sensitive pads to create a standalone, digitally controllable boost voltage regulator with a digital readout. If you're a keen programmer, you might be interested in testing your own designs using this chip. It could be used as the basis of all sorts of devices.

You could leave off most of the components and use the board to experiment with the bare chip, although we already presented a 'breakout board' that does that in October (siliconchip.au/Article/15506). Most recent 8-bit, 20-pin PIC microcontrollers have a similar pin layout, so this board could possibly be used with them too.

We purchased some PIC16F18146 chips in SOIC packages for this project and potentially for use in other projects. We chose that one over the others we looked at in October because it has more peripherals than the PIC16F18045, and importantly, it was available in a SOIC package (that isn't hard to solder) at the time.

The PIC16F17146 differs only in that it also has an internal op amp peripheral. That could be handy for some designs, but we shall have to see when stock becomes available to design a project around it.

The Digital Boost Regulator PCB suits all three of the aforementioned chips if you wish to experiment with them instead.

However, the other chips will need slightly different code to work, and we will leave that as an exercise for the reader.

The working principle of the boost circuit on this board is not novel. What is different is that instead of using a dedicated boost controller IC, we are simply configuring some of the PIC16F18146's internal peripherals to perform the same role.

Most dedicated switchmode controller ICs have more features, such as current limiting and short-circuit protection, that this design lacks. We have specified our circuit modestly to keep it simple.

Note that a dedicated chip will probably have a better control algorithm and thus tighter voltage regulation. While our design is not bulletproof, it is a working proof-of-concept that is usable in many roles.

Features & Specifications

- Onboard digitally controllable boost (voltage step-up) converter from 5V to up to 20V
- Output power of up to 0.5W (output current depends on selected voltage)
- Capacitive touchpad interface
- Four-digit LED display
- Breaks out all microcontroller pins to headers

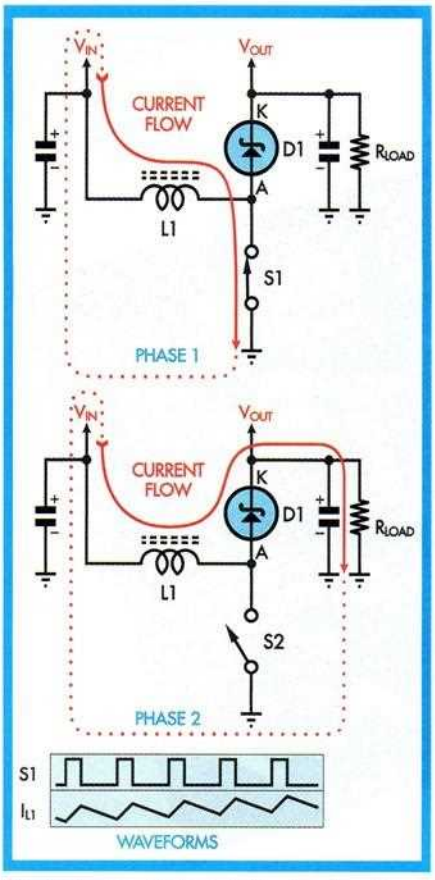


Fig.1: in a switched inductor boost circuit, energy is stored in the inductor's magnetic field when current flows through it. As the magnetic field collapses, it drives current to the output via the diode. By changing the switch duty cycle, the average energy in the inductor can be changed, controlling the output voltage.

This design is a way to show how valuable these advanced device peripherals can be. In particular, the configurable logic cells (CLCs) allow events to be responded to without requiring any processor attention.

We're only using a very small subset of the peripherals, so it won't seriously impact the chip's ability to perform other tasks if you were to use it for the basis of a design. For example, the PIC16F18146 has two DACs and two comparators, but we only use one of each.

Boost regulator

Fig.1 shows the basic arrangement of the inductor-based boost circuit we are implementing.

If the switch is closed, as shown at the top of the diagram, current from the incoming supply flows through inductor L1 to ground, charging the inductor's magnetic field. When the switch opens, the inductor continues to pass current, but it is diverted via diode D1 to the capacitor and load on the right-hand side.

Consider the case when the switch stays open. Due to the diode drop, the output voltage settles just below the incoming supply. This is the minimum output voltage; such a circuit cannot deliver a voltage much lower than the incoming supply.

If the switch spends some of its time closed, the average inductor current is higher and thus, the output voltage increases. The theoretical maximum (disregarding efficiency factors such as resistance and voltage drops across the diode) is equal to the supply voltage divided by the switch's open duty cycle. So if the duty cycle is 50%, the voltage output is (in theory) double the input.

Theoretically, if the duty cycle drops to 10% open (which is the same as 90% closed), the output voltage will be ten times the input voltage. However, with such a high boost ratio, the peak inductor current becomes so high that the output deviates substantially from the theoretical voltage.

Circuit details

Fig.2 shows the full circuit of our Digital Boost Regulator and breakout board.

IC1 is the PIC16F18146 microcontroller with a 10kΩ resistor pulling its $\overline{\text{MCLR}}$ pin (pin 4) to its supply rail to prevent spurious resets. A 100nF supply bypass capacitor is provided for stable operation.

CON1 and CON2 are possible sources for the supply voltage. CON1 is a standard mini-USB socket with only its power pins connected. The circuit nominally runs on 5V and is perfectly happy with anything from 4.5V to 5.5V, as might come from a USB power supply.

CON2 is used to connect a programmer, such as an PICkit 4 or Snap, which can also supply power (the Snap requires a modification to do so).

Q1 performs the role of the switch from Fig.1; the 10kΩ resistor from its gate to ground holds it off when there is no signal from the microcontroller (eg, during programming).

A capacitor on the supply side of L1 provides a stable, local power supply for the boost circuit from the 5V rail. The output capacitor, downstream of the diode's cathode, is supplemented by a pair of resistors forming a voltage divider.

This allows the microcontroller to sense an output voltage that might be higher than it could otherwise accept. This divided voltage is taken to a pin on IC1 that can be configured as an input to the internal comparator. The divided voltage can also be sampled by the analog-to-digital converter (ADC) peripheral, so we can measure the output voltage.

The output voltage on the capacitor is also taken to two-pin header CON4 so that you can feed it elsewhere.

TP1-TP3 are connected to PCB touch pads. They aren't external components but are formed from PCB traces designed to effect a change in capacitance when touched (the capacitors shown attached to the 'switches' represent the capacitance between the tracks). They each connect to an ADC-enabled pin of IC1. 17 of the 20 pins on the PIC16F18146 can be connected to the ADC.

Finally, LED1 is a four-digit seven-segment display connected to the remaining pins, configured as digital I/Os to drive the display in a multiplexed manner. Each of the eight segments (including the decimal point) has a series resistor for current limiting.

Firmware

Fig.3 shows how the internal peripheral blocks are configured to run the boost regulator.

Timer 1 is set running from the instruction clock. The comparator can be set to synchronise with this clock. We do this to prevent the comparator from oscillating at a high frequency when the output is near the setpoint.

The firmware also starts one of the PWM peripherals, set to operate at a 20% off and 80% on duty cycle. This puts a theoretical upper limit on the boost voltage that can be achieved, around five times the input voltage.

The PWM output is not sent to an I/O pin, but instead routed via an internal multiplexer to one of the CLC instances.

The FVR is set up to provide a 2.048V reference to one of the DACs (digital-to-analog converters). The DAC is enabled and is internally connected to the non-inverting input of the comparator. The 8-bit DAC can thus apply a voltage from 0 to 2.040V in 8mV steps.

In practice, the FVR reference is not precisely 2.048V. The stated accuracy is 4%, but the factory measured value can be read from the chip's DIA (device information area).

With a 10:1 (10kΩ/1kΩ) divider, the output range is about 22.44V in 88mV steps. The upper limit of the boost circuit with an 80% duty cycle is around 25V, depending on the supply voltage. So we should be able to achieve 20V at the boost output easily, and that's what we've specified.

The inverting input of the comparator is connected to the divided output voltage. Being an analog input, this can be one of four software-selectable pins. The comparator output is not exposed externally, although it could be. It is instead fed to one of the CLCs alongside the PWM signal.

The CLC is configured to simply provide a logical AND of the comparator output and the PWM signal. This is about the simplest possible application of the CLC.

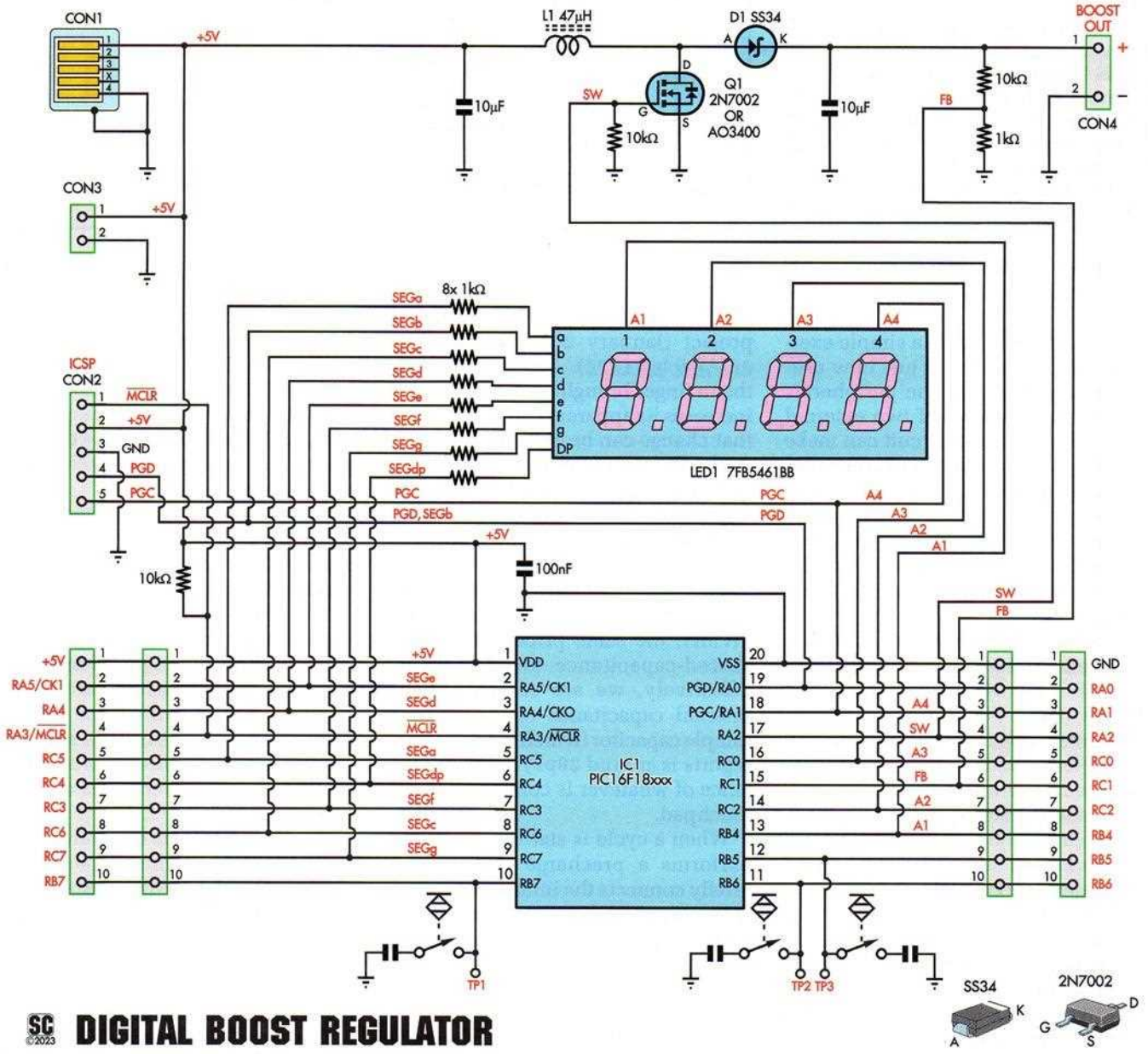
The output of the CLC AND gate is fed to one of the I/O pins and thus to the gate of the Mosfet. Since it is a digital signal, we could map it to any one of the 17 I/O pins on the PIC16F18146.

At power-on, assuming the DAC output is set to a sufficient level, the divided output voltage is well below the DAC setting. So the comparator output is high, and the Mosfet drive signal follows the PWM signal.

When the voltage rises above the setpoint, the comparator output drops low, and the Mosfet drive is shut off until the voltage decays below the setpoint.

We can change the output voltage simply by altering the DAC value. So the processor does not need to spend any time handling the boost converter unless it wishes to change the settings.

The Timer 1 synchronisation takes care of any jitter that might occur around the comparator's switching point, preventing the Mosfet from



DIGITAL BOOST REGULATOR

Fig.2: the lower section of the circuit shows the microcontroller connected to the rows of 'breakout' headers, along with the 7-segment LED display and the three touchpads. The boost circuitry at the top is driven by circuitry hidden inside IC1 (shown in Fig.3).

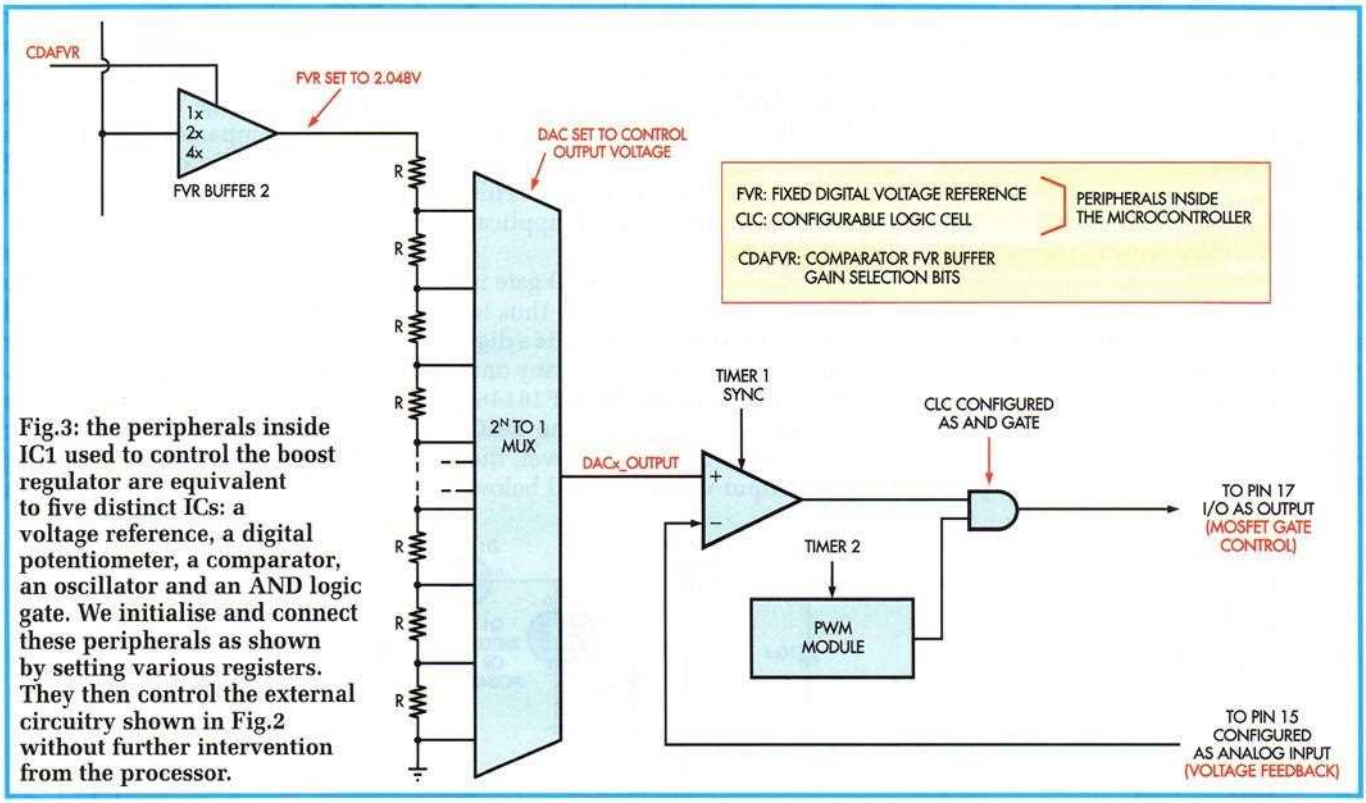


Fig.3: the peripherals inside IC1 used to control the boost regulator are equivalent to five distinct ICs: a voltage reference, a digital potentiometer, a comparator, an oscillator and an AND logic gate. We initialise and connect these peripherals as shown by setting various registers. They then control the external circuitry shown in Fig.2 without further intervention from the processor.

trying to switch too frequently by synchronising its state changes to the timer.

While it might seem a simple exercise, this demonstrates just how useful and configurable the peripherals can be. For the sake of two external pins, an application circuit can make do without a separate boost controller chip and, as a bonus, have a programmable voltage setpoint!

Once the peripherals have been initialised, this part of the circuit continues to run without taking up any more processor cycles.

Scope 1 shows typical operation with an output voltage of around 8.5V, including the Mosfet gate drive and drain voltage. The broader peaks are complete PWM cycles, while the narrower peaks are when the PWM cycle has been interrupted by the comparator sensing that the voltage is above the programmed threshold.

A dedicated boost control IC would dynamically control the pulse widths and provide more uniformity, giving a smoother output, better regulation and better efficiency, hence our conservative ratings for our boost circuit. Still, it does the job of regulating the output at the target voltage.

Touch sensing

We've discussed the operation of shared-capacitance touch sensing previously, with quite a bit of detail in the ATtiny816 Breakout Board project (January 2019; siliconchip.au/Article/11372). The principle is that a finger brought near a touchpad increases its apparent capacitance and that change can be detected.

The PIC16F18146 has an advanced ADCC or 'analog-to-digital converter with computation'. It can perform multiple samples and provide computed results based on these samples.

One of the modes supports the measurement of a capacitive voltage divider, the same principle used in shared-capacitance touch sensing. Effectively, we are comparing the internal capacitance of the ADCC's sample capacitor (which the data sheet reports is around 28pF) to the capacitance of whatever is connected to the touchpad.

When a cycle is started, the ADCC performs a precharge step, which briefly connects the internal capacitor to the supply voltage and the external pad to ground (and vice versa). The internal capacitor and pad are connected together during the sample phase of the ADCC cycle.

The numerical result of the conversion depends on the relative capacitance values. Higher values correlate to a higher capacitance at the external pad, as it can hold and thus contribute more charge from the precharge cycle.

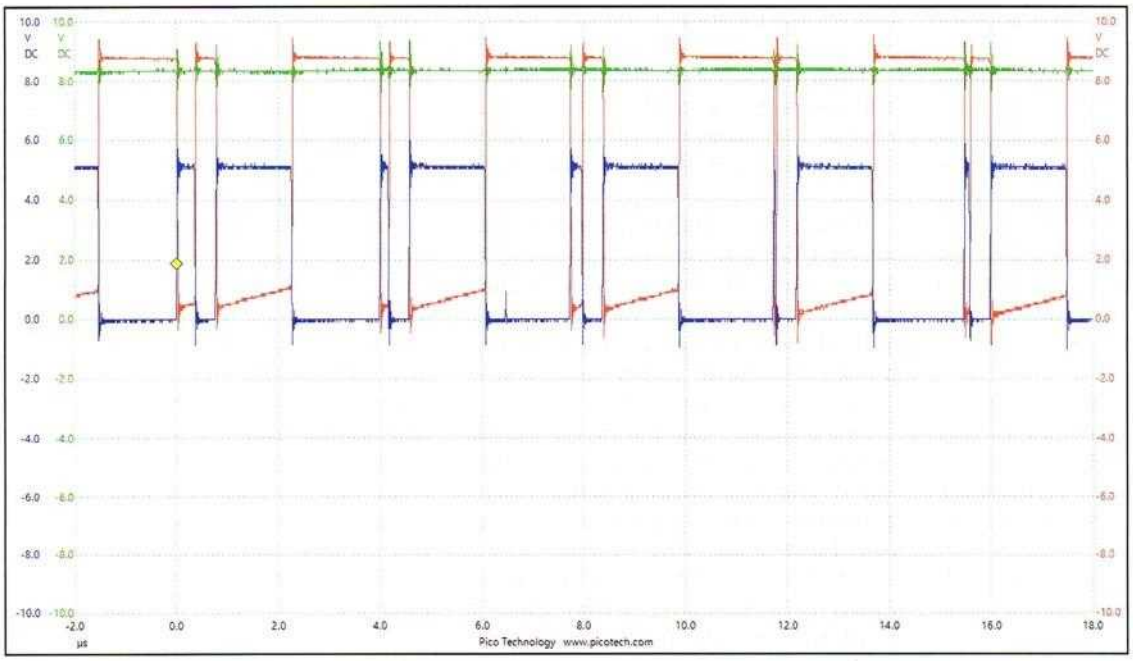
The PIC16F18146 can actually perform two measurements with inverted precharge polarities and report the difference. Once the ADCC is configured correctly, the channel (corresponding to one of the pads) is set, and the cycle starts. The result is read back a short while later.

Scope 2 shows the voltages on two touch pads during their cycles. You can see the two precharge and measurement steps for each pad.

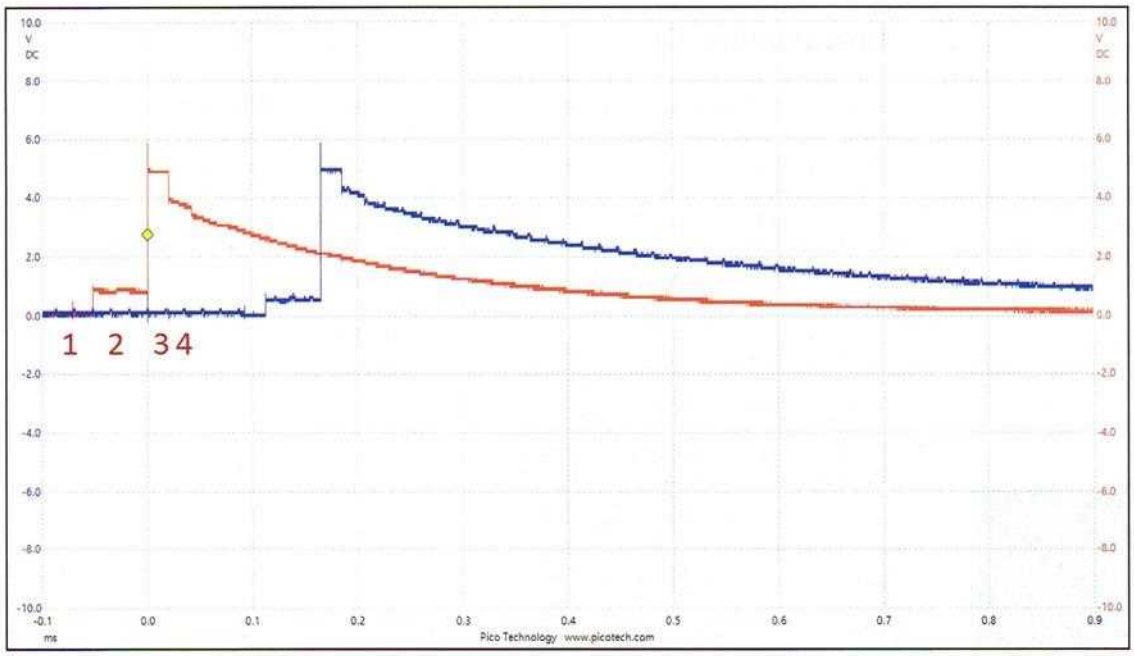
While we could calculate the actual capacitance from the reading, it is simpler and sufficient to pick a threshold value that can distinguish between the presence or absence of a finger near the pad. A brief software routine scans the pads and sets the values in an array to whether or not a touch was detected on each pad.

The other job of the firmware is multiplexed driving of the 7-segment LED display. For this, a timer interrupt is set to trigger 240 times per second. The display is blanked at each interrupt, and the output pins are changed to display the next digit in turn.

As it is a common-anode (CA) display, one of the four anodes is pulled high, while the remainder are left floating. Any segments to be lit on that digit are pulled low. The 60Hz



Scope 1: the blue trace shows the signal from the microcontroller to drive the gate of Q1 while the boost circuit is delivering 8.5V under load (green trace). The red trace is the voltage at the anode of D1. Dedicated boost controller chips typically change their duty cycle dynamically to control the output, while this circuit uses a fixed duty cycle modulated to limit the voltage.



Scope 2: the voltages at the I/O pins for two touchpads during the ADCC sampling cycle. The period labelled "1" is precharge while "2" indicates sampling. "3" and "4" are the same phases but with a positive precharge. Note how the stage 2 and 4 levels for the blue trace are further apart than for the red trace; that pad is being touched, and it is that difference that the ADCC reports.

update rate combined with the persistence of vision makes the display appear steady.

After construction is complete, we'll discuss the actual use and operation of the default firmware.

Construction

The following assumes that you want to build the Boost Breakout as described above. You could instead omit some parts and make a custom circuit by adding parts or connections to the breakout headers while using some or all of the included features.

The Digital Boost Regulator and breakout board is built on a double-sided PCB coded 24110224 that measures 50 × 89mm (see Fig.4). It uses practically all surface-mounting parts, so you should have flux paste, tweezers, a magnifier, a fine-tipped iron and some solder-wicking braid on hand. The flux will generate smoke, so use fume extraction or work outside to avoid breathing it in.

Start by fitting USB socket CON1. Place flux on the pads, then rest the socket on top. This part has lugs that will locate it correctly, so alignment shouldn't be difficult.

Clean the iron tip and apply some fresh solder to it. Touch the iron to the small pads and allow the solder to flow onto them. Only the two longer pads need to be soldered. If you form a bridge, use the braid and extra flux to remove it. Then solder the four larger pads around the sides of the shell to secure it mechanically.

Apply flux to the pads on the PCB, then fit IC1. Rest it in place, tack one lead and confirm that it is flat and aligned with all the pins. Also ensure that the divot or notch marking pin 1 is at the upper left as per the PCB silkscreen markings. When everything is aligned, solder the remaining pins.

Add some flux to the rest of the pads for the surface mounting parts. Q1 is the only transistor and should

be orientated as shown. The solitary diode D1 must be aligned with its cathode stripe to the right. The remaining parts are not polarised.

Use the same technique of soldering one lead and checking that the part is correctly positioned before soldering the remaining leads.

The two 10µF capacitors are near L1 and D1, while the 100nF capacitor is above IC1. Fit these next, being careful not to mix them up as they won't have markings.

There are only two different resistor values, but take care not to mix them up. Most of the 1kΩ resistors are grouped together near CON1; these are the current limiting resistors for the LED segments.

The last surface-mounting part is L1. Turn up your iron temperature a little, if possible, as this part has more thermal mass than the others. Add a thin layer of flux paste to its pads then, as for the smaller parts, tack one side, check the position and then solder the other leads.

Refresh any solder joints that look dry or rough by adding more flux and touching a clean iron tip. The solder should flow and smooth out.

Before fitting the remaining through-hole parts, clean the PCB of excess flux using a recommended solvent and allow it to evaporate.

Then check the alignment of LED1, being sure to orientate it as per our photos and overlays. Solder it from the back of the PCB and trim the leads close.

If you want to fit CON3 (for a 5V supply) or CON4 (to run the boosted voltage elsewhere), these can be header pins or sockets. If you like, you could add 10-way socket headers to the breakout pads to allow breadboard jumper wires to be used.

CON2 is only needed for in-circuit programming of IC1, so it can be omitted if you are working with a programmed chip, such as you would purchase from the SILICON CHIP Online Shop, and don't plan to experiment with the code. A right-angled header is recommended if you do fit CON2.

Programming IC1

If this is necessary, you can use a PICkit 4 or Snap programmer. The Snap will require power to be supplied, which can come via CON1.

You will need a relatively recent version of the MPLAB X IDE or IPE and the PIC16F1xxxx device family pack (DFP). We're using MPLAB X v6.00. If you wish to experiment with the software, you'll also need the XC8 v2.40 compiler.

Although the programming pins are also used to drive the LED display, they don't interfere with programming. At worst, there is faint ghosting on the LED display when the programmer is connected. We didn't run into any problems with programming the chip after the board was complete, although it didn't seem possible to perform debugging.

Connect your programmer to CON2 and upload the 2411022A.HEX file using the MPLAB X IPE.

We did run into one odd bug, and you might, too; the programming software reports that 0x3112 is an invalid device ID, even though the data sheet indicates that this is the correct device ID for the PIC16F18146. If you get the same error message with that exact value (see Screen 1), it is safe to ignore it.

You can continue to use the programmer to supply power, but the PICkit 4 cannot provide much current and won't be very useful for running the boost regulator. For that, you'll need to connect an external 5V supply, which could be as simple as a USB cable from a computer or charger.

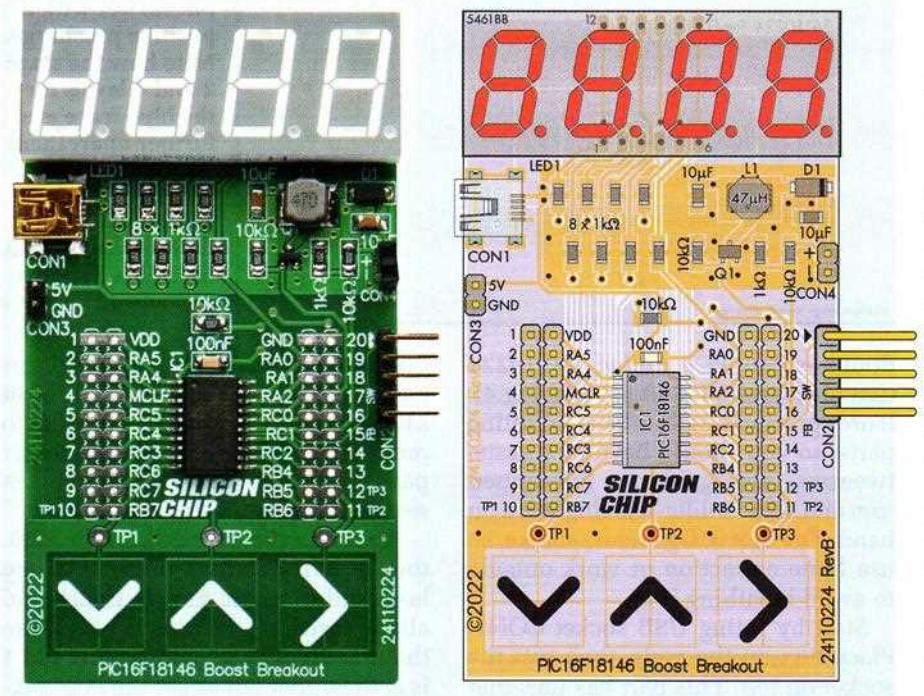


Fig.4: the Digital Boost Regulator mainly uses SMD parts, but they are all fairly easy to work with. Watch the orientation of the diode, IC1 and LED display, and you should have few troubles. If you omit all parts except IC1 and its two adjacent passives, you can use the PCB as a breakout board that suits many recent 8-bit PICs in 20-pin SOIC packages.

Operation

Assuming you have a 5V supply connected, you should see the display reading around 4.70 (the units are always volts) with the rightmost decimal point also lit. You can connect a multimeter to CON4 to check the output voltage.

If the displayed or measured voltage is much higher than the input, there may be a problem, so you should shut down the Boost Breakout and check the construction. The limited duty cycle should prevent the output from going way too high if there is a problem with the feedback system.

This default display shows the output voltage while the rightmost decimal point indicates that the boost circuit is enabled. If the supply voltage drops too low (below 4V), the output will switch off until the supply voltage increases above 4.5V.

As newly programmed, the boost circuit is enabled, but with a target of 0V, so the output voltage is simply the supply less the drop due to the diode.

Pressing and holding the > button under TP3 will cause the display to

Parts List – Digital Boost Regulator

1 double-sided PCB coded 24110224, 50 × 89mm
1 SMD mini USB socket (CON1)
1 5-way right-angle pin header (CON2; **optional**, for ICSP)
1 2-way pin header (CON3; **optional**)
1 2-way pin header or socket (CON4; **optional**)
1 47µH 1A 6×6mm inductor (L1) **[eg, Taiyo Yuden NR6045T470M]**

Semiconductors
1 PIC16F18146-I/SO programmed with 2411022A.HEX, wide SOIC-20 (IC1)
1 14mm/0.56in blue common-anode 4-digit 7-segment LED display (LED1) **[eg, 7FB5461BB]**
1 SS34 or similar 40V 3A schottky diode, DO-214AB (D1)
1 2N7002P, 2N7002K or AO3400 N-channel Mosfet, SOT-23 (Q1)

Capacitors *(all SMD M3216/1206-size X7R ceramic)*
2 10µF 25V+ 1 100nF 50V

Resistors *(all SMD M3216/1206-size 1% 1/8W)*
3 10kΩ 9 1kΩ

SC6597 Kit ($30 + postage)
A complete kit with all the parts listed above (including the optional components). The microcontroller is supplied pre-programmed.

switch to the setpoint display and start flashing 0.00. You can change the setpoint by holding one of the up or down buttons while holding the > button. The change happens straight away.

Each step of the setpoint corresponds to one step of the DAC output. The displayed voltages are calculated based on the internal voltage reference values from the device information area, so the steps are not uniform (due to rounding) and the maximums might not align. Still, you should have no trouble setting and achieving a 20V output.

Releasing the > button will return to the actual voltage output display. You should see the output tracking the setpoint as long as it is above 5V. The output will float a bit high with a light (or no) load as the boost circuit does not shut off until the output voltage is above the setpoint.

Pressing the up and down buttons together will display "b" and the supply voltage.

Finally, if all three buttons are pressed simultaneously, all segments will flash on, and the setpoint is saved to EEPROM so that it is used by default at power-up. The safest way to do this is to hold the up and down buttons and then press the > button. That way, the setpoint can't change.

If all the segments don't light up, the saved value may be the same as setpoint, meaning it doesn't need to write to the EEPROM. If it did, that would cause extra write cycles (and wear) on the EEPROM.

If you find the Boost Breakout is not responding to touches or is flashing when no touch pads are pressed, then be sure that you don't have anything connected to the touchpad I/O pins, especially circuitry that may affect the capacitances.

Code details

We tested our prototype with various power supplies, both grounded and ungrounded and chose our touch sensitivity values based on those tests. These are the TOUCH_DOWN and TOUCH_UP values near the top of the "io.h" file. Having two values allows us to provide some hysteresis and thus debounce the buttons.

Since the measured value increases on a touch, the sensitivity can be reduced by increasing these values. Conversely, the sensitivity can be increased by lowering the values. You shouldn't need to make any changes if you are using the board as designed, but if you try to make touchpads by running wires from TP1-TP3, the capacitances may change.

No doubt some people will be interested in using bits of our code, especially the boost and touch sections. So we've tried to make it modular and section the code into dedicated functions for each.

The doTouch() function calls several other functions to check the state of the touch pads and store them in the t[] array. The other functions include initADCcvd() and getADCcvd().

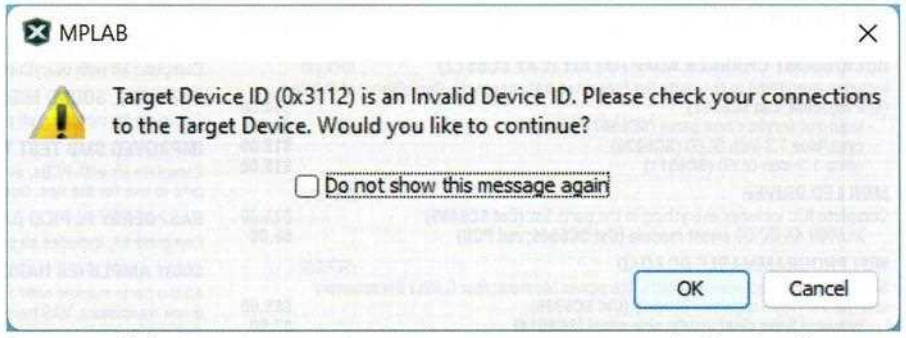
The boostInit() function sets up the peripherals used for the boost controller. Controlling it simply requires the DAC to be set using the DAC1DATL register after it is enabled by clearing the TRIS bit of the RA2 port pin (which has been defined as SWPIN).

Minimal circuitry

If you want to use the board as a breakout for the PIC16F18146, only the 100nF capacitor and 10kΩ resistor adjacent to IC1 are needed for operation. The LED display and its eight 1kΩ resistors can be omitted to free up 12 I/O pins.

Q1, L1, D1, CON4 and the associated passives, which include a 1kΩ, two 10kΩ resistors and two 10µF capacitors constitute the components that provide the boost feature. Leaving these off will free up two IO pins.

Naturally, you will need to change the code to work without the display, and if you need a further three I/O pins, you will need another control method to replace the touch pads. However, they can't easily be physically removed without sawing off the bottom section of the PCB. SC


MPLAB
Target Device ID (0x3112) is an Invalid Device ID. Please check your connections to the Target Device. Would you like to continue?
Do not show this message again
OK
Cancel

Screen 1: if, during programming, you see an error message indicating that 0x3112 is an invalid device ID for the PIC16F18146, you can safely ignore it. The data sheet shows that 0x3112 is the correct ID.

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PIC32MX170F256D-501P/T	44-pin Micromite Mk2 (Aug14), 4DoF Simulation Seat (Sep19)
PIC32MX170F256B-50I/SP	Micromite LCD BackPack V1-V3 (Feb16 / May17 / Aug19) RCL Box (Jun20), Digital Lighting Controller Micromite Master (Nov20) Advanced GPS Computer (Jun21), Touchscreen Digital Preamp (Sep21)
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Includes the PCB, programmed micro, OLED and all other on-board parts **$75.00**

BUCK-BOOST LED DRIVER KIT (CAT SC6292) *(JUN 22)*
Complete kit with everything needed to assemble the board **$80.00**

SPECTRAL SOUND MIDI SYNTH KIT (CAT SC6261) *(JUN 22)*
Complete kit including all programmed PICs (no case or power supply) **$200.00**

IMPROVED SMD TEST TWEEZERS KIT (CAT SC5934) *(APR 22)*
Complete kit with PCBs, all onboard parts, new microcontroller and gold-plated header pins to use for the tips. Does not include a lithium coin cell **$35.00**

RASPBERRY PI PICO BACKPACK KIT (CAT SC6075) *(MAR 22)*
Complete kit, includes all parts except the optional DS3231 IC **$80.00**

500W AMPLIFIER HARD-TO-GET PARTS (CAT SC6019) *(APR 22)*
All the parts marked with a red dot in the parts list, including the 12 output transistors, driver transistors, VAS transistors, input pair (2SA1312), BAV21 & UF4003 diodes, TL431 ICs, 75pF capacitor, E96 series resistors and 10kΩ 1W resistor **$190.00**

HUMMINGBIRD AMPLIFIER (CAT SC6021) *(DEC 21)*
Hard-to-get parts includes: two 0.22Ω 5W resistors; plus one each of an MJE15034G, MJE15035G, KSC3503DS & 220pF 250V C0G ceramic capacitor **$15.00**

SMD TRAINER COMPLETE KIT (CAT SC5260) *(DEC 21)*
Includes PCB & all on-board components, except for a TQFP-64 footprint device **$20.00**

*Prices valid for month of magazine issue only. All prices in Australian dollars and include GST where applicable. # P&P prices are within Australia. Overseas? Place an order on our website for a quote.

PRINTED CIRCUIT BOARDS & CASE PIECES

For a complete list, go to siliconchip.com.au/Shop/8

PRINTED CIRCUIT BOARD TO SUIT PROJECT	DATE	PCB CODE	Price
AUDIO/RF SIGNAL TRACER	JUN97	04106971	$5.00
HEAVY-DUTY 240VAC MOTOR SPEED CONTROLLER	NOV97	10311971	$7.50
TINY LED XMAS TREE (GREEN/RED/WHITE)	NOV19	16111191	$2.50
BOOKSHELF SPEAKER PASSIVE CROSSOVER	JAN20	01101201	$10.00
↳ SUBWOOFER ACTIVE CROSSOVER	JAN20	01101202	$7.50
ARDUINO DCC BASE STATION	JAN20	09207181	$5.00
NUTUBE VALVE PREAMPLIFIER	JAN20	01112191	$10.00
TUNEABLE HF PREAMPLIFIER	JAN20	06110191	$2.50
4G REMOTE MONITORING STATION	FEB20	27111191	$5.00
LOW-DISTORTION DDS (SET OF 5 BOARDS)	FEB20	01106192-6	$20.00
NUTUBE GUITAR DISTORTION / OVERDRIVE PEDAL	MAR20	01102201	$7.50
THERMAL REGULATOR INTERFACE SHIELD	MAR20	21109181	$5.00
↳ PELTIER DRIVER SHIELD	MAR20	21109182	$5.00
DIY REFLOW OVEN CONTROLLER (SET OF 3 PCBS)	APR20	01106193/5/6	$12.50
7-BAND MONO EQUALISER	APR20	01104201	$7.50
↳ STEREO EQUALISER	APR20	01104202	$7.50
REFERENCE SIGNAL DISTRIBUTOR	APR20	CSE200103	$7.50
H-FIELD TRANSANALYSER	MAY20	06102201	$10.00
CAR ALTIMETER	MAY20	05105201	$5.00
RCL BOX RESISTOR BOARD	JUN20	04104201	$7.50
↳ CAPACITOR / INDUCTOR BOARD	JUN20	04104202	$7.50
ROADIES' TEST GENERATOR SMD VERSION	JUN20	01005201	$2.50
↳ THROUGH-HOLE VERSION	JUN20	01005202	$5.00
COLOUR MAXIMITE 2 PCB (BLUE)	JUL20	07107201	$10.00
↳ FRONT & REAR PANELS (BLACK)	JUL20	SC5500	$10.00
OL' TIMER II PCB (RED, BLUE OR BLACK)	JUL20	19104201	$5.00
↳ ACRYLIC CASE PIECES / SPACER (BLACK)	JUL20	SC5448	$7.50
IR REMOTE CONTROL ASSISTANT PCB (JAYCAR)	JUL20	15005201	$5.00
↳ ALTRONICS VERSION	JUL20	15005202	$5.00
USB SUPERCODEC	AUG20	01106201	$12.50
↳ BALANCED ATTENUATOR	NOV20	01106202	$7.50
SWITCHMODE 78XX REPLACEMENT	AUG20	18105201	$2.50
WIDEBAND DIGITAL RF POWER METER	AUG20	04106201	$5.00
ULTRASONIC CLEANER MAIN PCB	SEP20	04105201	$7.50
↳ FRONT PANEL	SEP20	04105202	$5.00
NIGHT KEEPER LIGHTHOUSE	SEP20	08110201	$5.00
SHIRT POCKET AUDIO OSCILLATOR	SEP20	01110201	$2.50
↳ 8-PIN ATtiny PROGRAMMING ADAPTOR	SEP20	01110202	$1.50
D1 MINI LCD WIFI BACKPACK	OCT20	24106121	$5.00
FLEXIBLE DIGITAL LIGHTING CONTROLLER SLAVE	OCT20	16110202	$20.00
↳ FRONT PANEL (BLACK)	OCT20	16110203	$20.00
LED XMAS ORNAMENTS	NOV20	16111191-9	$3.00
30 LED STACKABLE STAR	NOV20	16109201	$12.50
↳ RGB VERSION (BLACK)	NOV20	16109202	$12.50
DIGITAL LIGHTING MICROMITE MASTER	NOV20	16110201	$5.00
↳ CP2102 ADAPTOR	NOV20	16110204	$2.50
BATTERY VINTAGE RADIO POWER SUPPLY	DEC20	11111201	$7.50
DUAL BATTERY LIFESAVER	DEC20	11111202	$2.50
DIGITAL LIGHTING CONTROLLER LED SLAVE	DEC20	16110205	$5.00
BK1198 AM/FM/SW RADIO	JAN21	CSE200902A	$10.00
MINIHEART HEARTBEAT SIMULATOR	JAN21	01109201	$5.00
I'M BUSY GO AWAY (DOOR WARNING)	JAN21	16112201	$2.50
BATTERY MULTI LOGGER	FEB21	11106201	$5.00
ELECTRONIC WIND CHIMES	FEB21	23011201	$10.00
ARDUINO 0-14V POWER SUPPLY SHIELD	FEB21	18106201	$5.00
HIGH-CURRENT BATTERY BALANCER (4-LAYERS)	MAR21	14102211	$12.50
MINI ISOLATED SERIAL LINK	MAR21	24102211	$2.50
REFINED FULL-WAVE MOTOR SPEED CONTROLLER	APR21	10102211	$7.50
DIGITAL FX UNIT PCB (POTENTIOMETER-BASED)	APR21	01102211	$7.50
↳ SWITCH-BASED	APR21	01102212	$7.50
ARDUINO MIDI SHIELD	APR21	23101211	$5.00
↳ 8X8 TACTILE PUSHBUTTON SWITCH MATRIX	APR21	23101212	$10.00
HYBRID LAB POWER SUPPLY CONTROL PCB	MAY21	18104211	$10.00
↳ REGULATOR PCB	MAY21	18104212	$7.50
VARIAC MAINS VOLTAGE REGULATION	MAY21	10103211	$7.50
ADVANCED GPS COMPUTER	JUN21	05102211	$7.50
PIC PROGRAMMING HELPER 8-PIN PCB	JUN21	24106211	$5.00
↳ 8/14/20-PIN PCB	JUN21	24106212	$7.50
ARCADE MINI PONG	JUN21	08105211	$35.00
Si473x FM/AM/SW DIGITAL RADIO	JUL21	CSE210301C	$7.50
20A DC MOTOR SPEED CONTROLLER	JUL21	11006211	$7.50
MODEL RAILWAY LEVEL CROSSING	JUL21	09108211	$5.00
COLOUR MAXIMITE 2 GEN2 (4 LAYERS)	AUG21	07108211	$15.00

PRINTED CIRCUIT BOARD TO SUIT PROJECT	DATE	PCB CODE	Price
BATTERY MANAGER SWITCH MODULE	AUG21	11104211	$5.00
↳ I/O EXPANDER	AUG21	11104212	$2.50
NANO TV PONG	AUG21	08105212	$2.50
LINEAR MIDI KEYBOARD (8 KEYS) + 2 JOINERS	AUG21	23101213	$5.00
↳ JOINER ONLY (1pc)	AUG21	23101214	$1.00
TOUCHSCREEN DIGITAL PREAMP	SEP21	01103191	$12.50
↳ RIBBON CABLE / IR ADAPTOR	SEP21	01103192	$2.50
2-/3-WAY ACTIVE CROSSOVER	OCT21	01109211	$15.00
TELE-COM INTERCOM	OCT21	12110121	$30.00
SMD TEST TWEEZERS (3 PCB SET)	OCT21	04106211/2	$10.00
USB CABLE TESTER MAIN PCB	NOV21	04108211	$7.50
↳ FRONT PANEL (GREEN)	NOV21	04108212	$5.00
MODEL RAILWAY CARRIAGE LIGHTS	NOV21	09109211	$2.50
HUMMINGBIRD AMPLIFIER	DEC21	01111211	$5.00
DIGITAL LIGHTING CONTROLLER TRANSLATOR	DEC21	16110206	$5.00
SMD TRAINER	DEC21	29106211	$5.00
8-LED METRONOME	JAN22	23111211	$5.00
10-LED METRONOME	JAN22	23111212	$7.50
REMOTE CONTROL RANGE EXTENDER UHF-TO-IR	JAN22	15109211	$2.50
↳ IR-TO-UHF	JAN22	15109212	$2.50
6-CHANNEL LOUDSPEAKER PROTECTOR	JAN22	01101221	$7.50
↳ 4-CHANNEL	JAN22	01101222	$5.00
FAN CONTROLLER & LOUDSPEAKER PROTECTOR	FEB22	01102221	$5.00
SOLID STATE TESLA COIL (SET OF 2 PCBs)	FEB22	26112211/2	$7.50
REMOTE GATE CONTROLLER	FEB22	11009121	$20.00
DUAL HYBRID POWER SUPPLY SET (2 REGULATORS)	FEB22	SC6204	$25.00
↳ REGULATOR	FEB22	18107211	$7.50
↳ FRONT PANEL	FEB22	18107212	$2.50
↳ CPU	FEB22	01106193	$5.00
↳ LCD ADAPTOR	FEB22	01106196	$2.50
↳ ACRYLIC LCD BEZEL	FEB22	SC6309	$5.00
RASPBERRY PI PICO BACKPACK	MAR22	07101221	$5.00
AMPLIFIER CLIPPING DETECTOR	MAR22	01112211	$2.50
CAPACITOR DISCHARGE WELDER POWER SUPPLY	MAR22	29103221	$5.00
↳ CONTROL PCB	MAR22	29103222	$5.00
↳ ENERGY STORAGE MODULE (ESM) PCB	MAR22	29103223	$5.00
500W AMPLIFIER	APR22	01107021	$25.00
MODEL RAILWAY SEMAPHORE CONTROL PCB	APR22	09103221	$2.50
↳ SIGNAL FLAG (RED)	APR22	09103222	$2.50
AM-FM DDS SIGNAL GENERATOR	MAY22	CSE211002	$7.50
SLOT MACHINE	MAY22	08105221	$5.00
HIGH-POWER BUCK-BOOST LED DRIVER	JUN22	16103221	$5.00
ARDUINO PROGRAMMABLE LOAD	JUN22	04105221	$5.00
SPECTRAL SOUND MIDI SYNTHESISER	JUN22	01106221	$7.50
REV. UNIVERSAL BATTERY CHARGE CONTROLLER	JUN22	04107192	$7.50
VGA PICOMITE	JUL22	07107221	$5.00
SECURE REMOTE MAINS SWITCH RECEIVER	JUL22	10109211	$7.50
↳ TRANSMITTER (1.0MM THICKNESS)	JUL22	10109212	$2.50
MULTIMETER CALIBRATOR	JUL22	04107221	$5.00
110dB RF ATTENUATOR	JUL22	CSE211003	$5.00
WIDE-RANGE OHMMETER	AUG22	04109221	$7.50
WiFi PROGRAMMABLE DC LOAD MAIN PCB	SEP22	04108221	$7.50
↳ DAUGHTER BOARD	SEP22	04108222	$5.00
↳ CONTROL BOARD	SEP22	18104212	$10.00
MINI LED DRIVER	SEP22	16106221	$2.50
NEW GPS-SYNCHRONISED ANALOG CLOCK	SEP22	19109221	$5.00
BUCK/BOOST CHARGER ADAPTOR	OCT22	14108221	$5.00
30V 2A BENCH SUPPLY MAIN PCB	OCT22	04105221	$7.50
↳ FRONT PANEL CONTROL PCB	OCT22	04105222	$2.50
AUTO TRAIN CONTROLLER	OCT22	09109221	$2.50
↳ TRAIN CHUFF SOUND GENERATOR	OCT22	09109222	$2.50
PIC16F18xxx BREAKOUT BOARD (DIP-VERSION)	OCT22	24110222	$2.50
↳ SOIC-VERSION	OCT22	24110225	$2.50
AVR64DD32 BREAKOUT BOARD	OCT22	24110223	$2.50
LC METER MK3	NOV22	CSE220503C	$7.50
↳ ADAPTOR BOARD	NOV22	CSE200603	$2.50
DC TRANSIENT SUPPLY FILTER	NOV22	08108221	$5.00
TINY LED ICICLE (WHITE)	NOV22	16111192	$2.50
NEW PCBs			
DUAL-CHANNEL BREADBOARD PSU	**DEC22**	**04112221**	**$5.00**
↳ DISPLAY BOARD	**DEC22**	**04112222**	**$5.00**
DIGITAL BOOST REGULATOR	**DEC22**	**24110224**	**$5.00**
ACTIVE MONITOR SPEAKERS POWER SUPPLY	**DEC22**	**01112221**	**$10.00**

We also sell the SILICON CHIP PDFs on USB, RTV&H USB, Vintage Radio USB and more at siliconchip.com.au/Shop/3

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

mmPi add-on for Raspberry Pi

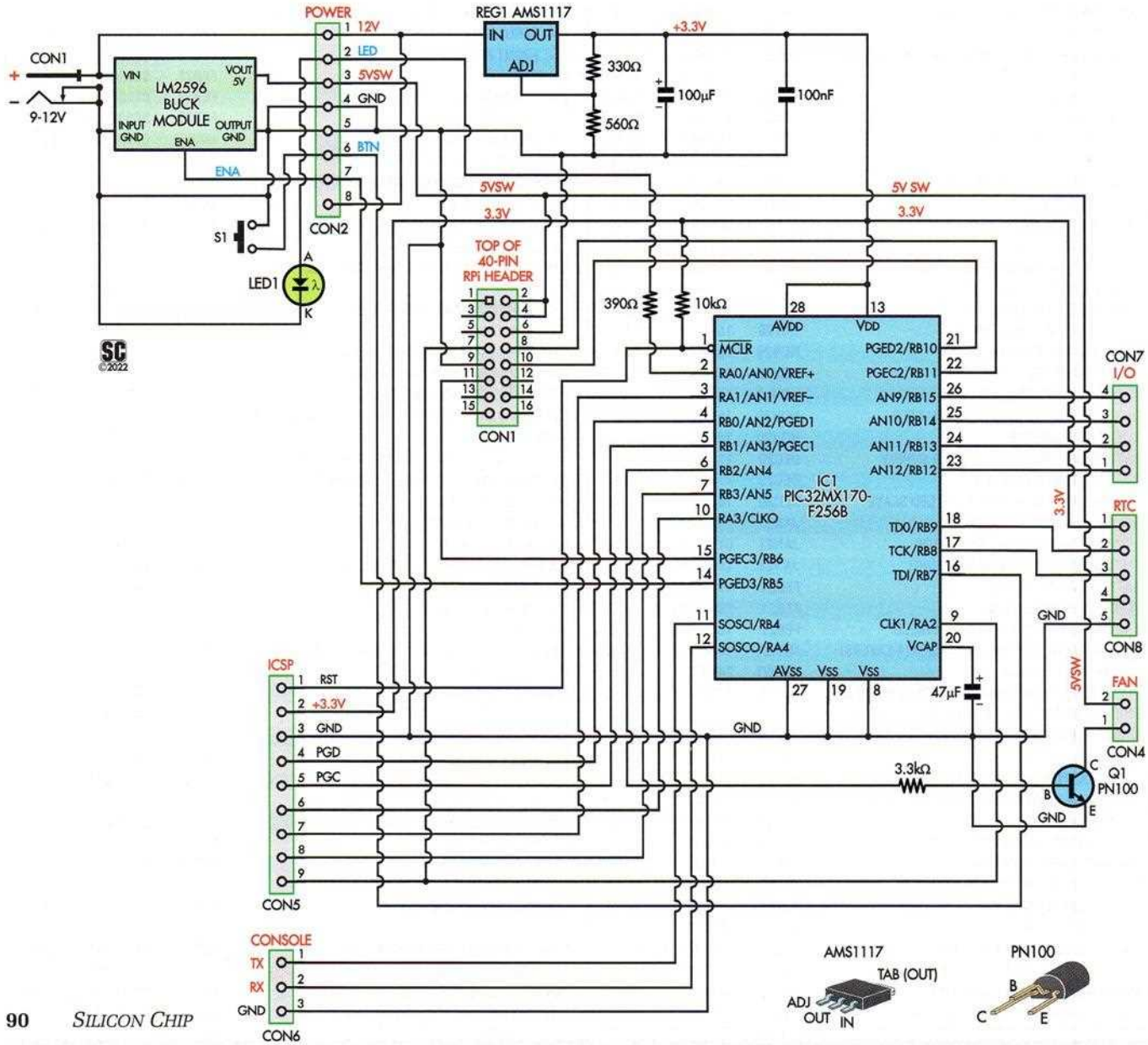
The mmPi is an add-on "hat" PCB for Raspberry Pi series boards (Zero to Pi 4). It adds shutdown and on/off/standby power supply control. As a bonus, it also adds up to six analog inputs, a real-time clock and program space to write your own code routines (in BASIC), interfacing with the Raspberry Pi via its serial port. The mmPi uses Geoff Graham's MMBasic (see http://geoffg.net).

The mmPi has a Microchip PIC32MX170 microcontroller programmed with MMBasic and running the "mmPi.bas" program. The program's main purpose is to control a DC-to-DC power module via its shutdown/enable pin.

Pushbutton S1, connected to the circuit board, initiates a shutdown or restart sequence via the mmPi, which provides the timing and hardware control to gracefully shut down or restart the Raspberry Pi. The pushbutton shutdown/restart action requires a long press (>2 seconds), so the button can be used for a user program with shorter press actions.

The program also provides user feedback via LED1 and intelligent cooling fan control (CON4) based on the Raspberry Pi CPU temperature.

When in standby, no power goes to the Raspberry Pi; the only power usage is the throttled back PIC32MX170, its low-power regulator and the quiescent current used by the DC to DC power module. This standby current is less than ~9mA.



The Standby status is retained if the low-voltage supply is completely removed from the whole mmPi/Raspberry Pi combination; it will not restart when power is re-applied until the button is pressed.

The DC-to-DC converter module is based on an LM2596 IC and needs to be modified for this project. First, disconnect the right-most pin of the LM2596 (pin 5; ENA) from the PCB, eg, by cutting the lead. Then solder a thin wire to the stump of pin 5 on the regulator and run it to pin 7 of CON2 on the mmPi PCB.

The mmPi PCB connects to the first 16 pins of the Raspberry Pi 26/40 pin connector via CON1, and only eight are actually used. 5V power goes to the Raspberry Pi from the DC-DC converter via pins 2, 4, 6 & 9. The serial port, UART0, is on pins 9 and 10.

Pins 7 & 11 of CON1 (GPIO4 & GPIO17) are used for Pi control signals (rpi-running, rpi-shutdown). These signals must be configured in the Raspberry Pi by editing the config.txt file. To do this, open /boot/config.txt in nano (or your preferred editor). You need to be the root user to do this, so prefix the command with "sudo".

Copy or re-type the below into the file. Lines starting with "#" are just comments.

```
# This sets up the ability for a pushbutton
# switch to shut it down:
# Also the Raspberry Pi's status is
# signalled via GPIO Pin4
dtoverlay=gpio-shutdown,gpio_pin=17
dtoverlay=gpio-poweroff,gpiopin=4,active_low=1
```

Assuming you're using nano, save and exit the file with CTRL-X, then Y, then Enter.

To have your enclosure fan controlled by mmPi using the Raspberry Pi's CPU temperature, you need to create a script on the Pi (eg, called "cputemp"):

```
#!/bin/bash
temp='cat /sys/class/thermal/thermal_zone0/temp'
echo "{pi-temp:$(($temp/1000))}" > /dev/ttyAMA0
echo "{pi-temp:$(($temp/1000))}"
```

Save and exit the file again with CTRL-X, Y and Enter (again, assuming you're using nano).

Lastly, create a crontab entry to execute this program every minute using the "crontab -e" command. Append the following entry:

```
* * * * * /bin/bash/cputemp
```

Save and close the file. That's assuming you named the script "cputemp" and placed it in your home directory.

Programming the PIC32

This can be achieved in a few ways. The easiest method is to start with a chip pre-programmed with MMBasic and load the "mmPi.bas" program, part of the download package for this design. That package also includes the mmPi PCB Gerber files. You can find a HEX file to program the PIC32 with MMBasic at siliconchip.com.au/Shop/6/74 or on Geoff Graham's website, linked earlier.

An enclosure has been designed for a Raspberry Pi 4 with an mmPi hat. It is 3D printed and the STL files are included in the download package, but also see: www.thingiverse.com/thing:5143440

Michael Ogden,
Yarragon, Vic ($80).

Two different positive DC outputs from a centre-tapped transformer

Frequently, both +12V and +5V rails are required in mains-powered equipment. Generating the 5V rail directly from the 12V rail using a linear regulator incurs heavy power dissipation for all but the lightest loads – more power is always wasted than is used by the load.

Here the transformer secondary is rectified by the full-wave bridge formed from diodes D1-D4, filtered by capacitor C1, then fed to the 12V regulator.

At the same time, D3 and D4 form a full-wave centre-tapped rectifier producing a pulsating positive potential at the centre tap that is filtered by C2 and sent to the 5V regulator.

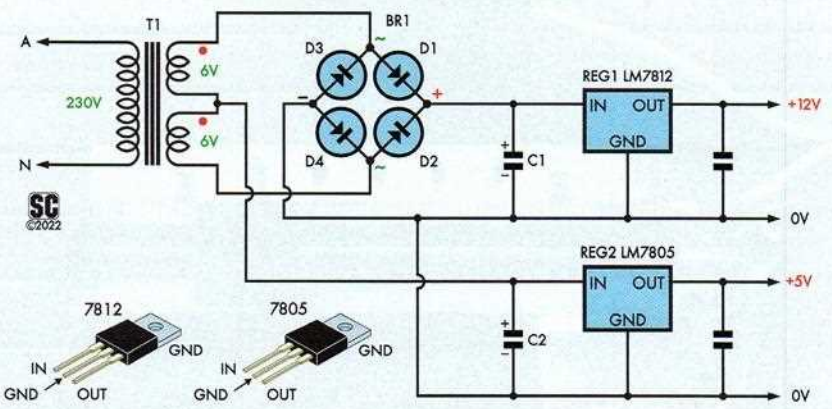
The resulting peak voltage across C2 is half that of C1, so the 5V regulator has to deal with a much lower voltage differential, resulting in lower dissipation. The negative terminals of C1 and C2 are common.

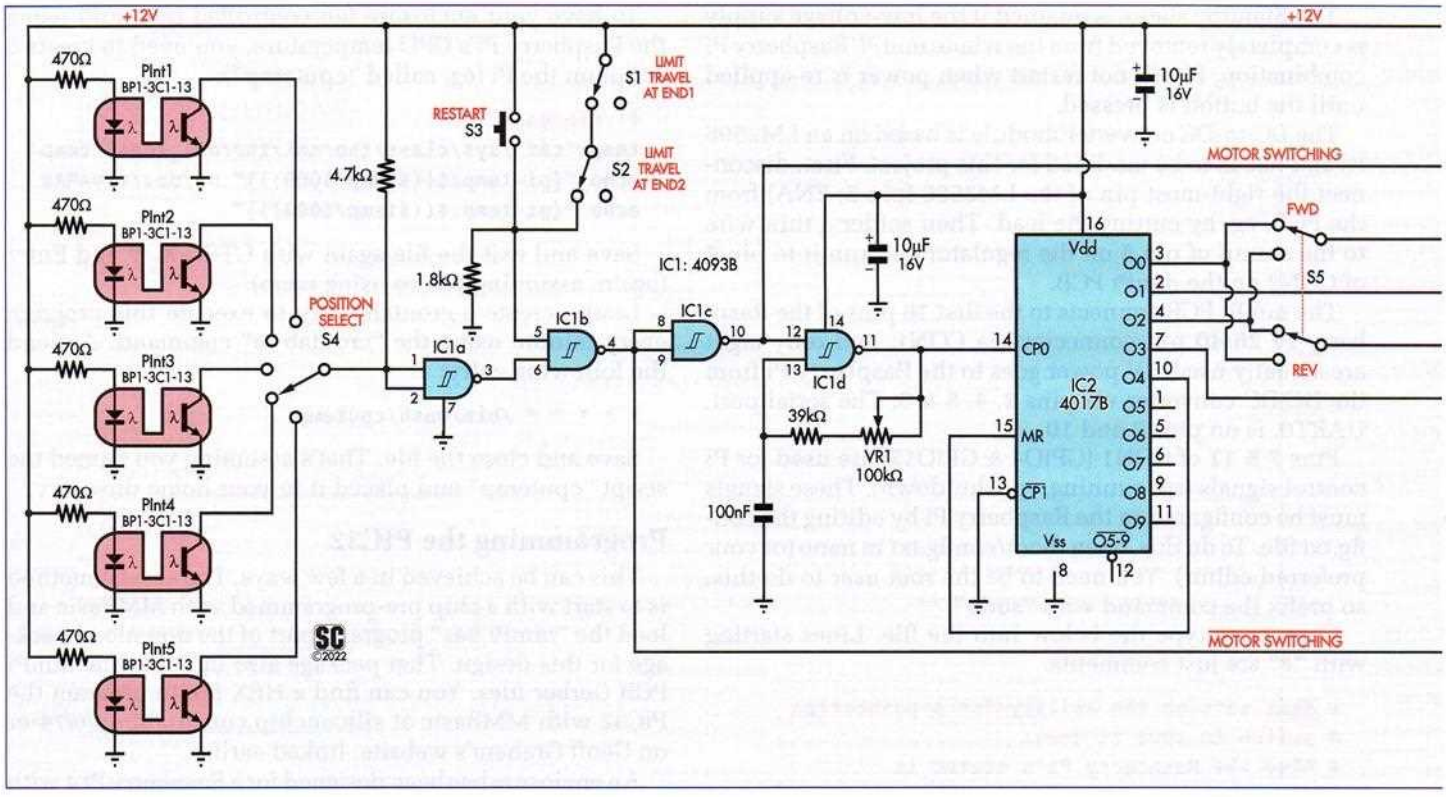
Importantly, there is no restriction on the relative amount of current drawn from each rail. If needed, the 5V rail can be the high current supply, while 12V provides a low current or any ratio required. The transformer VA, rectifier ratings, and filter capacitor values can be adjusted accordingly.

The same concept can be applied to 12V/24V and 24V/48V configurations commonly seen in motor-drive systems. The lower voltage is usually regulated for the control circuitry, and the higher one is left unregulated for driving the motor.

As is standard with centre tapped full-wave rectifiers, a bifilar wound secondary is preferred over a tapped single winding to avoid the possibility of a turns mismatch causing the transformer core to 'walk' up the magnetisation curve and thereby increase transformer heating losses.

Mark Hallinan,
Murwillumbah, NSW ($75).





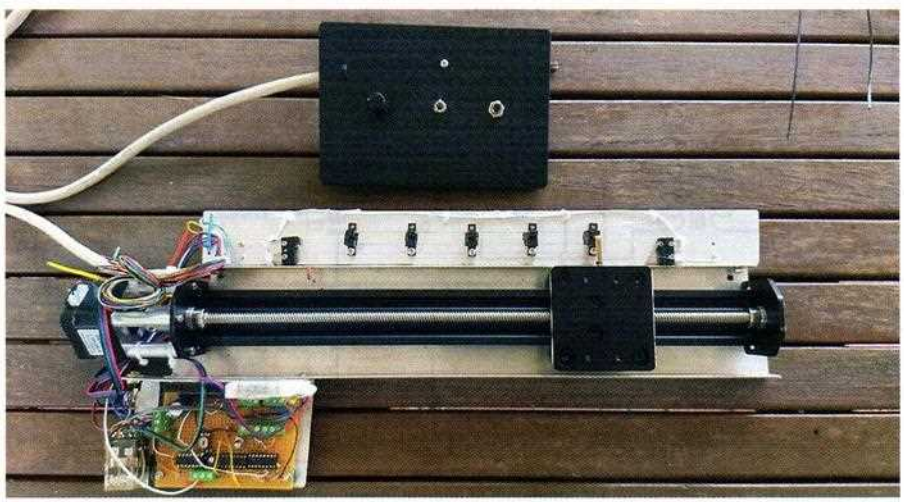
Traverser for photography or model railway

This design arose as the result of a request by a friend to build a control system that could move a table with five sections of railway track. Each track was to be used for parking a locomotive and, when moved into alignment with the main rail, would allow the locomotive to enter or exit the main layout. The alignment of the rails had to be within a fraction of a millimetre and reproducible.

He also wanted a simple circuit with no microprocessors that could be repaired by anyone else without special tools.

You can also use this sort of rig for amazing time lapse photography by placing a camera on a moving platform and shifting it a tiny bit between each frame. The main change you'd need to make to my circuit for that application is to increase the RC constant of the oscillator to achieve very slow movement (you might even be able to use the pulses it generates to trigger the camera).

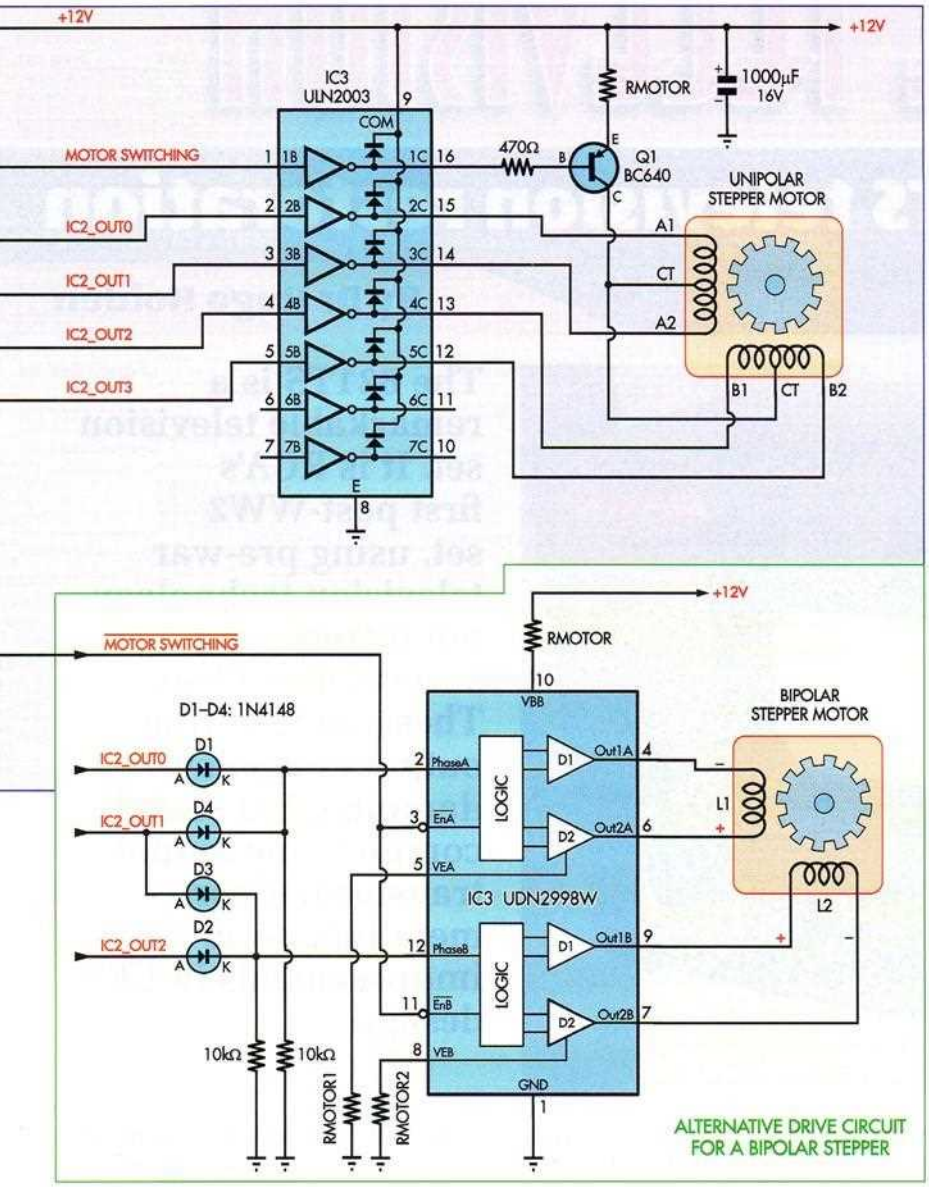
The necessary precision and torque is best achieved for either application using a screw-driven platform and a stepper motor drive. Fortunately, these are readily available at low cost, and we sourced a 300mm drive from banggood.com (item 1416716). Testing it with a photo-interrupter indicated that it could achieve a reproducibility better than 0.1mm.

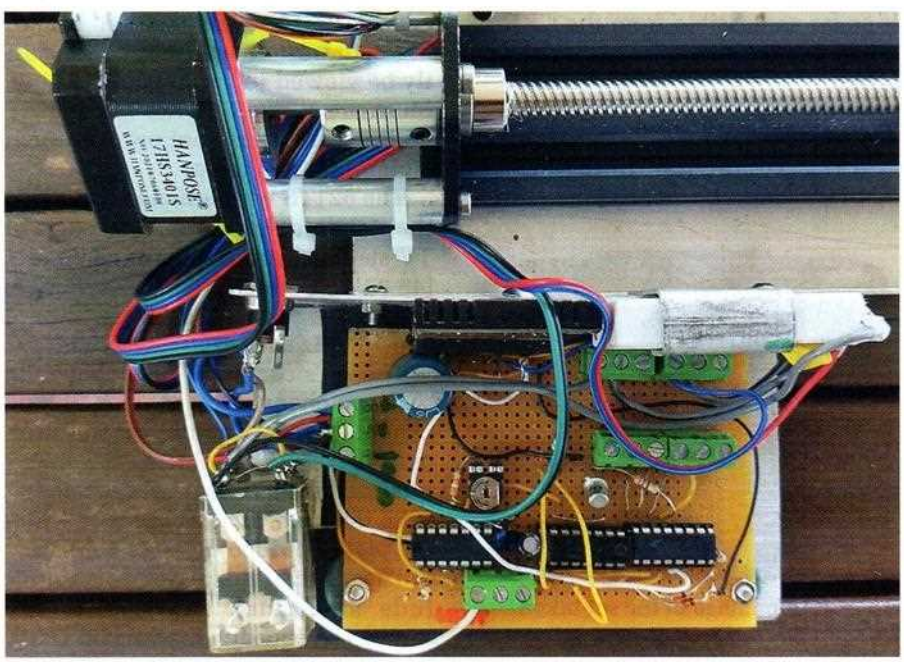


I designed drive circuitry that would work with either unipolar or bipolar motors. The correct position to stop the platform is defined by one of five photo-interrupters, each with its LED permanently lit for simplicity. The beams are interrupted by a thin phosphor bronze finger attached to the moving platform.

The position selector switch directs the signal to the selected photodiode, and only when the light beam is interrupted does the output go high to turn the motor off. This is achieved by inverting this signal with the first NAND gate (IC1a), and its output goes to the second gate, IC1b. The second input to this gate is held high by switches S1 and S2, which are used to limit the end travel of the platform.

The output of IC1b is inverted by the third gate, IC1c, and used to enable an oscillator built around IC1d. The oscillator output drives a 4017 decade counter, which is reset on the fifth count (when output Q4 goes high). Outputs O0-O3 are then used to drive the unipolar motor by activating the transistors in a ULN2003 in turn.





A fifth transistor in the ULN2003 is used to power a PNP transistor Q1 that switches the motor voltage supply. This ensures that the motor coils are not driven when the drive pulses are not present.

Switches S1 and S2 are simple microswitches positioned at the ends of the track so that they open if the platform reaches them. Switch S3 allows you to restart the motor briefly when the direction is reversed. The reversing switch, S5, changes the output sequence from 0, 1, 2, 3 to 0, 3, 2, 1.

A resistor is included in series with the motor power supply to limit the motor current if necessary. Otherwise, it can be linked out.

Most of the bipolar drive version circuitry shown in the panel is the same as in Fig.1. This is the version I used as the Banggood device came with a bipolar stepper motor. Motor driving is simplified by a UDN2998 dual H-bridge IC, chosen because I had it on hand; other similar devices could be used instead.

Control pulses are fed to the phase inputs; the phase A pattern is 1,1,0,0 while phase B is 0,1,1,0. This is achieved by ORing outputs O0 & O1 and O1 & O2 from the 4017 using four small-signal diodes.

Switching power to the motor is achieved using the UDN2998's enable inputs, which disables power to one half of each bridge when high, so motor activation is controlled by the output of IC1b. The motor direction can be reversed by transposing the connections to one of the coils in a similar arrangement to S5.

Once I'd assembled everything, I measured the locations of the four other stop positions with a micrometer over five measurements. They were within less than 0.1mm, about one motor step. However, the stop position was approximately 0.7mm different when moving in the opposite direction.

This is due to the interrupter slot width, but by placing the rails at an intermediate point, the traverser should stop within 0.3mm of the ideal point – more than adequate. I made some allowance for fine adjustment by only mounting the photo-interrupters with one screw. This permits them to be rotated slightly left or right.

Graham P. Jackman,
Melbourne, Vic ($100).

VINTAGE TELEVISION

1946 RCA 621TS television restoration

By Dr Hugo Holden

The 621TS is a remarkable television set. It is RCA's first post-WW2 set, using pre-war television technology but introducing several new ideas. These include line output efficiency damping, FM sound, complex line output transformer core metallurgy and improvements in CRT design.

The 1946 RCA 621TS set has a 7-inch (18cm) screen with a 7DP4 CRT. The 7DP4 has an 8kV maximum EHT voltage (typically 6kV), uses an ion trap magnet and provides a very bright, high-contrast picture.

The cabinet was designed by the respected industrial designer John Vassos in 1941. WW2 meant a six-year delay to get it to market. The model was quickly replaced by a 10-inch (25cm) set, the RCA 630TS, with a 10BP4 CRT.

The chassis of the set I acquired was in very poor and rusted condition, typical for its age – see Photo 1. It required a complete rebuild using similar techniques to those used in the HMV904 restoration (described in the November 2018 issue – see siliconchip.com.au/Article/11314).

In the post-war period, it became standard practice to enclose the line output transformer and EHT rectifier in a separate cage, in this case on the lower-right of the chassis. The power transformer at lower left was mounted on the chassis under-surface to keep it as far as possible from the CRT, to avoid magnetic interference with the beam.

TV overview

WW2 somewhat delayed the 621TS's development. One of its important new design elements was a 7-inch electromagnetically deflected CRT with a high final anode voltage of 7.5kV. This gave a bright, high-contrast image that could easily be viewed in good room lighting. Most pre-WW2 TVs ran lower EHT voltages and could not produce such a high-contrast image.

An example image of the set taken from an advertisement.

The 621TS was designed to receive the standard American VHF range of TV station frequencies for channel 1 (45.25MHz video carrier, 49.75MHz sound) to 13 (211.25MHz video, 215.75MHz sound).

The set's oscillator runs above the received channel frequencies. Taking channel 1 as an example, the Kallitron oscillator runs at 71MHz. The sound intermediate frequency (IF) emerging from the tuner is at 21.25MHz, while the picture (video) IF is 25.75MHz.

The picture (video) carrier is amplitude modulated (AM) while the sound is frequency modulated (FM),

compared to pre-WW2 TV sets which had AM sound.

The sound carrier wave was transmitted 4.5MHz higher than the vision carrier; they had not yet moved to 'inter-carrier sound'. In this system, the two carriers beat together at the video detector output to produce a 4.5MHz carrier wave, passing on to a 4.5MHz sound IF amplifier.

However, in the 621TS, the 21.25MHz sound IF carrier is taken directly from the converter coil into the sound IF. Only a few years later, most American TVs had moved to inter-carrier sound. The advantage was that the sound did not drift out of tune with variations in local oscillator frequency.

At the tail end of this amplifier is the FM detector, in this case, a discriminator type where the driving stage is designed to amplitude-limit the 4.5MHz carrier. Later, many manufacturers moved to a ratio detector design, which has the advantage of inherent amplitude limiting.

You can find the service manual with circuit diagrams etc at the Early Television Foundation website:

siliconchip.au/link/abge

Tuner

The tuner is a separate assembly very similar to the type of tuned box seen in practically all TV sets after 1946. However, it does not use a rotating drum; instead, it has an array of rotary switches.

The tuner is very elegant and is based on three 6J6 twin triodes. Based on one 6J6 dual triode (V1), the input stage is a para-phase (differential amplifier) that is neutralised by two small 1.5pF capacitors from the plate of one triode to the grid of the other. This design became very popular later in wideband oscilloscope circuits.

In this case, though, the anode loads are broadly tuned in the region of the received station frequency.

The received frequencies are then passed to the converter (mixer) stage, V2, using inductive link coupling. The converter also receives the signal from the local oscillator, again by inductive link coupling, and the signals are mixed in the plate circuits of both the triodes of the V2, which are connected together in the converter stage to feed the converter coil.

The converter stage has an astonishingly large converter coil with a large tuning slug. The coil assembly is close to 25mm in diameter and about 75mm tall.

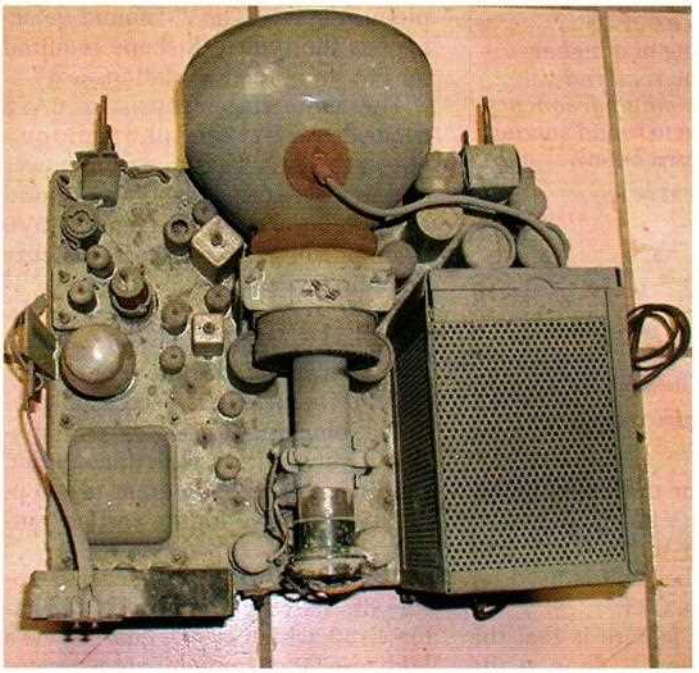


Photo 1: the chassis of the 621TS was acquired with a heaping of dust and rust.

Oscillator

The 6J6 twin triode local oscillator circuit around V3, shown in Fig.1, is pleasingly symmetrical. On its face, it could be regarded as an over-neutralised (unstable) para-phase amplifier which, with high feedback from each plate to the grid of the other triode via the 4.7pF capacitors, resembles a classic multi-vibrator circuit.

However, the load for each plate is a split resonant circuit which generates a negative resistance. If a negative resistance is applied across a resonant or tank circuit, it will oscillate. The arrangement is a "Kallitron oscillator" (sometimes spelled with one L, but it has two Ls in Terman's Radio Engineers' Handbook).

Video & audio IF stages

The video IF stage consists of a string of four stagger-tuned circuits based on 6AG5 pentodes V101, V102, V103 & V104. Like the 6J6, these revolutionary small 7-pin types would ultimately lead to the demise of their larger octal-base counterparts. A few years later, the 6AG5 turned out to be an excellent performer in the VHF turret tuner units of many brands of TV sets.

The stagger tuning (with correct adjustment) creates the bandpass characteristic of the video IF. In this set, the bandpass characteristic is very well described in the service manual (Fig.2). The bandpass characteristic is only in the order of 3MHz for the video, which is enough to support a fairly detailed picture on the relatively small screen.

Later, as the CRTs got bigger, the bandwidth had to increase to have good high-frequency picture detail. In RCA's next TV, the 630TS, they moved to a 10-inch CRT, and the video bandwidth was a little closer to 4MHz.

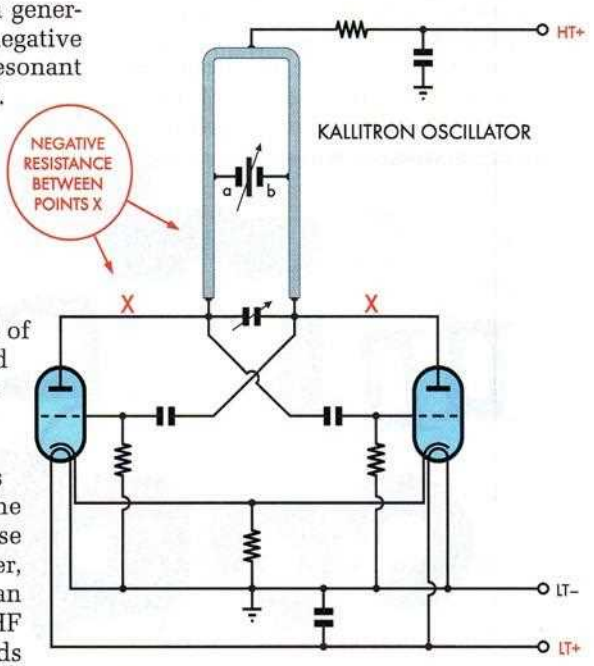
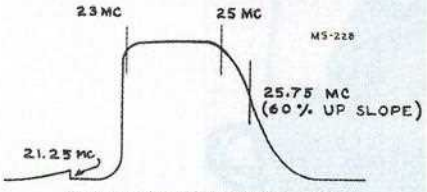


Fig.1: the oscillator section of the circuit, based on a 6J6 dual triode (V3).

Fig.2: with the receiver RF oscillator operating at a higher frequency than the received carrier, the intermediate frequency relation of picture to sound carrier is reversed as shown below.



Typical Overall Response Curve

The curve shown is typical of the picture IF amplifier response.

The output from the video detector, an octal 6H6 (V104A), passes to video preamplifier triode V105, half of a 6SN7. The other half is used for video output to the CRT.

One interesting feature is that the video DC restoration is done at the grid of this video output valve. The positive sync tips cause grid current, with the grid-cathode acting as a diode. This clamps the sync tip and the black level to a stable point. The anode of this valve is directly coupled into the grid of the 7DP4 CRT.

The plate load of the 6SN7b has both shunt and series peaking with inductors to maintain the frequency response required for the video signal. This became industry standard for the video output stage. The video background is unstable, depending on the image contrast, without direct coupling from the video detector and amplifier to the CRT or DC restoration.

The sound carrier frequency of 21.25MHz is filtered out by T101 to avoid any sound interfering with the picture signals. The FM sound detector has the typical S-shape required for FM sound demodulation.

The audio stages consist of 6AT6 triode driver V117 and 6K6 audio output stage V118. The maximum power output from a 6K6 is generally around 4W, similar to the more common 6V6 beam power valve, so there is plenty of audio power.

Vertical scan

This is handled by another 6SN7 (V107). One triode is used as a combined blocking oscillator and discharge valve with a small transformer, running at 60Hz. The other triode in the 6SN7 is used for the vertical output.

'Discharge' in this case refers to rapidly discharging a 'sawtooth' capacitor, C130, which is then charged via a high resistance source. This generates the sawtooth wave required for the scan. However, a trapezoidal wave is needed to develop a sawtooth current in an inductor with resistance, such as the vertical yoke coils.

This is created by placing a small resistor, typically less than 5kΩ (here R149 = 3.3kΩ) in series with the sawtooth capacitor. The vertical output transformer matches the output stage to the vertical yoke coils in the usual manner.

Horizontal scan and EHT generation

The horizontal oscillator, running at 15.75kHz, is also half of another 6SN7, V108. The oscillator is synchronised on a line-by-line basis from the sync pulses. By the late 1940s, this idea was abandoned in favour of an automatic frequency control circuit (AFC) with better noise immunity, operating on the same principles as a phase-locked loop (PLL).

The other triode in the same 6SN7 is used as a separate discharge valve. The drive then passes to a substantial power output valve (6BG6, V109) with a 0.9A heater. It is specifically designed to be a 'sweep valve' for horizontal output stages, withstanding very high peak anode voltages in the order of 6.6kV. Peaks of a few kV appear on the anode during flyback in this set.

The flyback circuit uses energy recovery damping (with 5V4 damper diode V111). See the following panel on "The evolution of the damper diode" for details.

This was a revolution in TV design, providing highly-efficient horizontal scanning using the stored magnetic energy from the right half of the scan to scan the left side. At the same time, it created the high voltage flyback pulse that could be stepped up to many kilovolts and be rectified, in this case with a 1B3 rectifier (V110) to run the CRT's final anode.

Before this idea of using the energy recovery diode, the scanning was less efficient, and the required damping wasted energy in resistors and sometimes diodes as heat.

Generally, because pre-WW2 sets had no high voltage spike in the horizontal scan output stages from which to derive EHT, they simply used a line transformer. Large filter capacitors were needed to remove the ripple, and the supplies were a lot more dangerous

Photos 2 & 3: the line output transformer (shown disassembled at left, and whole at right) has an advanced moulded iron core made of three parts. This was around the time most manufacturers were switching to ferrite-cored transformers.

Photo 4: the unrestored chassis without the CRT. The photo above shows a close-up of one of the valves with a lead shield.

as they could source higher currents and store more energy.

It is safer to have a flyback supply with a relatively high internal resistance to generate the few milliamps needed. A supply that can deliver more than 30mA at several kV is hazardous.

Contrary to what some believe, the charge stored on the bulb of a CRT after turn off is low and generally cannot harm a person as a one-off discharge. This is why, even with the set running, very few if any TV technicians have received a fatal shock from a flyback EHT supply for a CRT, as they can mostly only source relatively low currents.

Line output transformer

The line output transformer in this set is very interesting. It has an advanced moulded iron core made of three parts (it's visible disassembled in Photo 2 and assembled in Photo 3). The core is intermediate in appearance between a ferrite dust core and an iron core.

Laminated iron cores struggled to work well at the 15.75kHz horizontal scan frequency. However, some UK-made TV sets still used iron-cored line output transformers even in the post-war period. Within a decade after the 621TS was released, most American TV manufacturers had moved to ferrite-cored horizontal output transformers.

This basic design set the standard for practically all line output transformers to follow, complete with the two-turn winding for the EHT rectifier.

A dirty and rusty chassis

Photo 4 shows the unrestored chassis with the CRT removed, with a close-up after I had removed the superficial dust and dirt removed. One valve has a lead shield, with a spring clip holding it in place.

As is standard practice, I hollowed out the original wax paper capacitors and fitted new polyester types with double the original voltage ratings inside. I then poured polyester into each end to seal them up on alternate days.

After that, I had the chassis fine-bead blasted to remove all the rust, re-plated with 20-micron electro-less nickel, and lacquer coated. This helps to avoid corrosion and finger marks.

I rebuilt the tuner first. The tuner in this set is 'space age' sophisticated for 1946. Its features include a differential input RF amplifier with neutralisation based on a 6J6, another 6J6 Kallitron oscillator and the spectacular large mixer coil driven by the combined anode signals from another 6J6. The use of a combination of both ferromagnetic materials and brass slugs to tune the coils is also advanced.

The idea behind the large mixer coil (seen on the top of Photos 5 & 6) is to create a very high-Q, loosely coupled selective sound take-off. The large sound IF coil is spaced away from the former to avoid it being tuned by distributed capacitance; instead, it is tuned mainly by the 'high-Q' 62pF dog-bone ceramic capacitor across it.

The mixer anode coil for the video is broadly tuned and loaded by a 10kΩ resistor and the plate impedance of the 6J6 mixer valve.

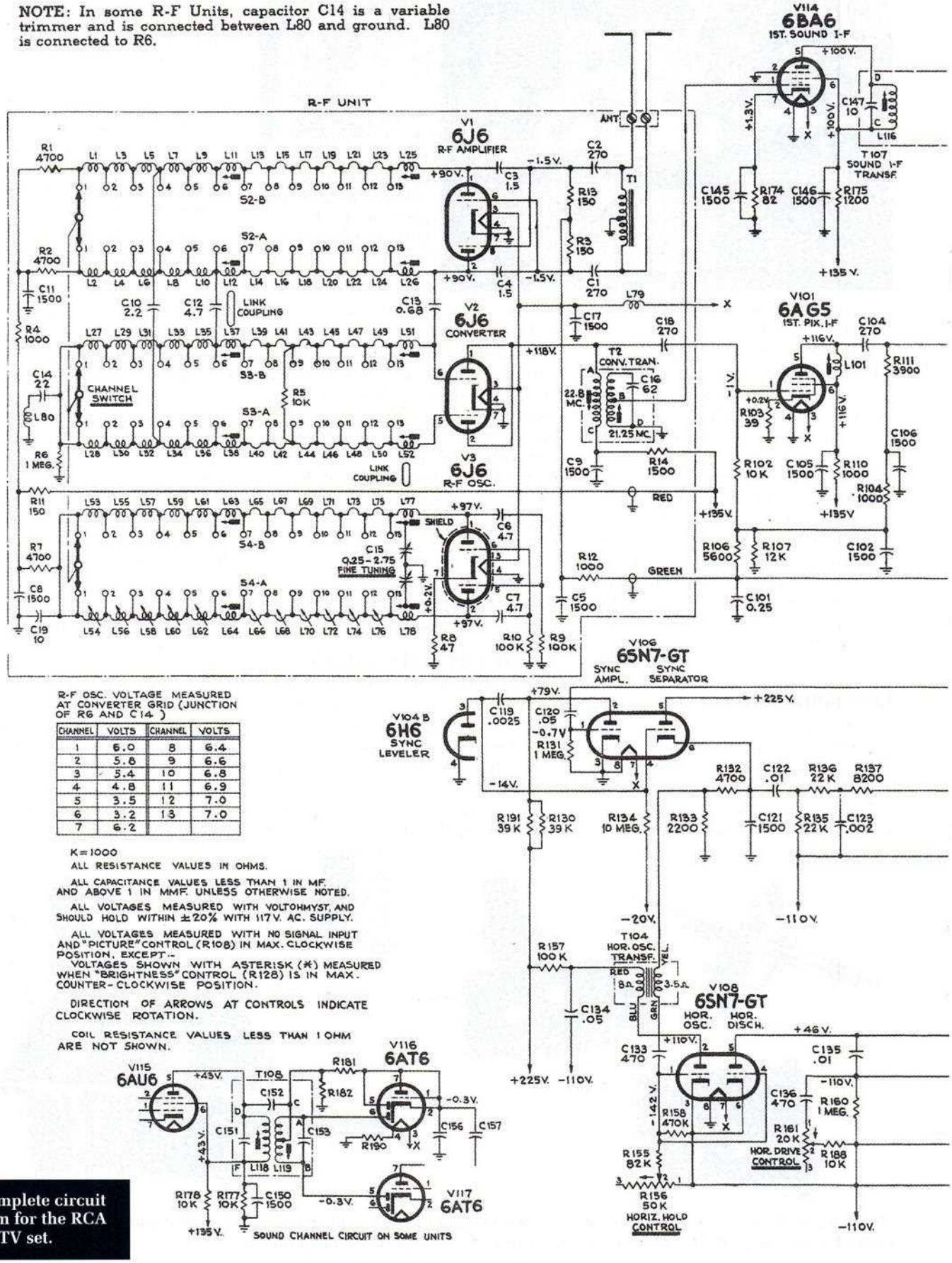
While restoring the tuner, I replaced most of the bypass/coupling capacitors with silver mica types, except the local oscillator feedback capacitors. I replaced those with 500V 4.7pF mil-spec dog-bone ceramic capacitors with the same temperature coefficient as the originals. The same goes for the

...continued on page 100

Photos 5 & 6: the disassembled (left) and assembled (right) RF tuner. The tuner knob has dual-control with the more protruded section providing station selection while the rest is used for fine tuning.

OVERALL SCHEMATIC DIAGRAM

NOTE: In some R-F Units, capacitor C14 is a variable trimmer and is connected between L80 and ground. L80 is connected to R6.



R-F OSC. VOLTAGE MEASURED AT CONVERTER GRID (JUNCTION OF R6 AND C14)

CHANNEL	VOLTS	CHANNEL	VOLTS
1	6.0	8	6.4
2	5.8	9	6.6
3	5.4	10	6.8
4	4.8	11	6.9
5	3.5	12	7.0
6	3.2	13	7.0
7	6.2		

K = 1000

ALL RESISTANCE VALUES IN OHMS.

ALL CAPACITANCE VALUES LESS THAN 1 IN MF. AND ABOVE 1 IN MMF. UNLESS OTHERWISE NOTED.

ALL VOLTAGES MEASURED WITH VOLTOHMYST, AND SHOULD HOLD WITHIN ±20% WITH 117 V. AC. SUPPLY.

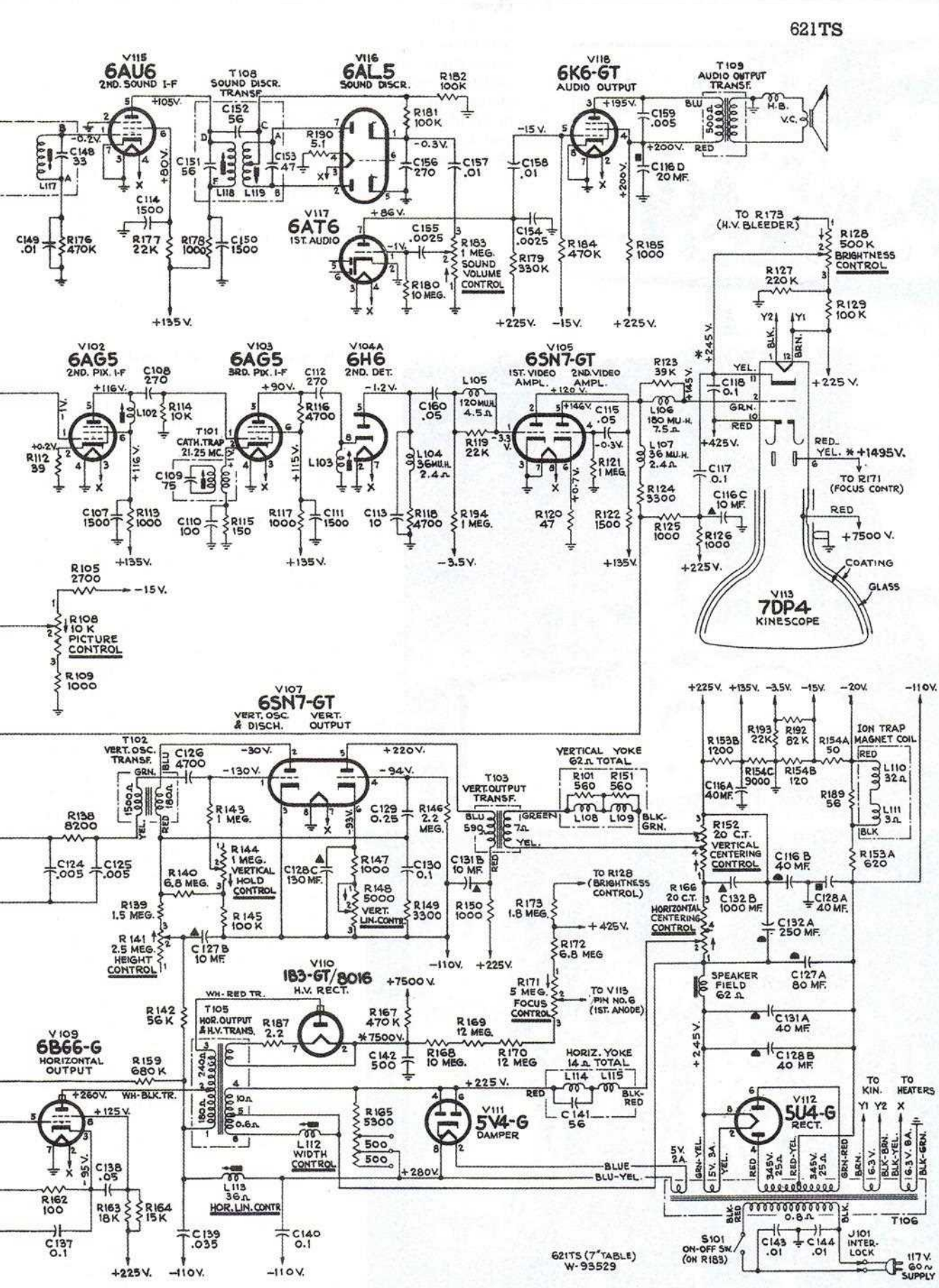
ALL VOLTAGES MEASURED WITH NO SIGNAL INPUT AND "PICTURE" CONTROL (R108) IN MAX. CLOCKWISE POSITION, EXCEPT:-
VOLTAGES SHOWN WITH ASTERISK (*) MEASURED WHEN "BRIGHTNESS" CONTROL (R128) IS IN MAX. COUNTER-CLOCKWISE POSITION.

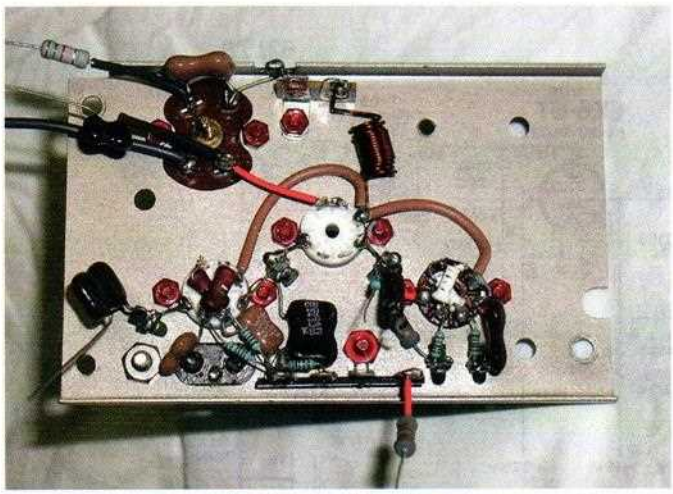
DIRECTION OF ARROWS AT CONTROLS INDICATE CLOCKWISE ROTATION.

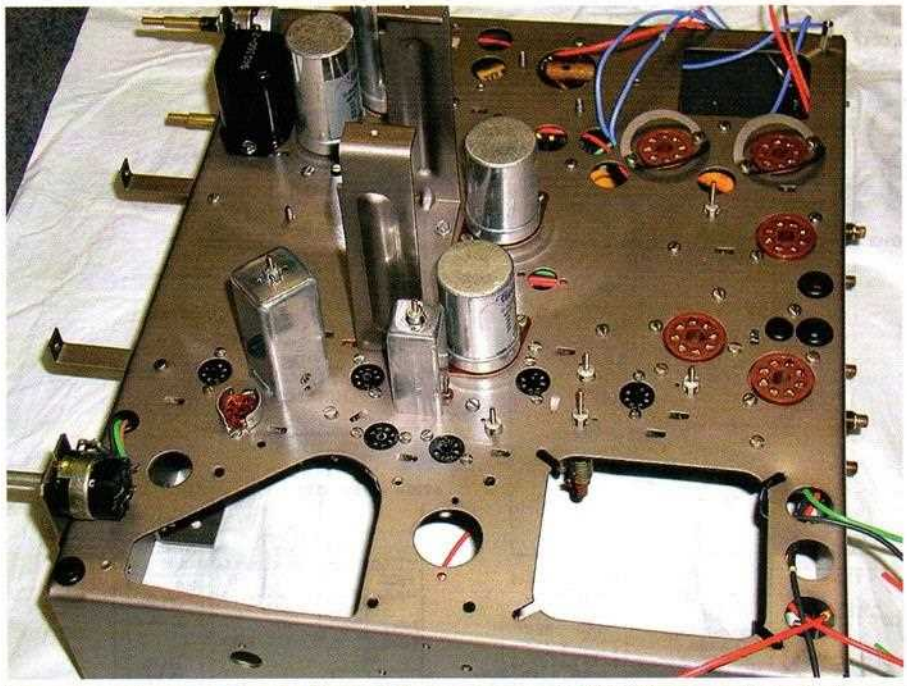
COIL RESISTANCE VALUES LESS THAN 1 OHM ARE NOT SHOWN.

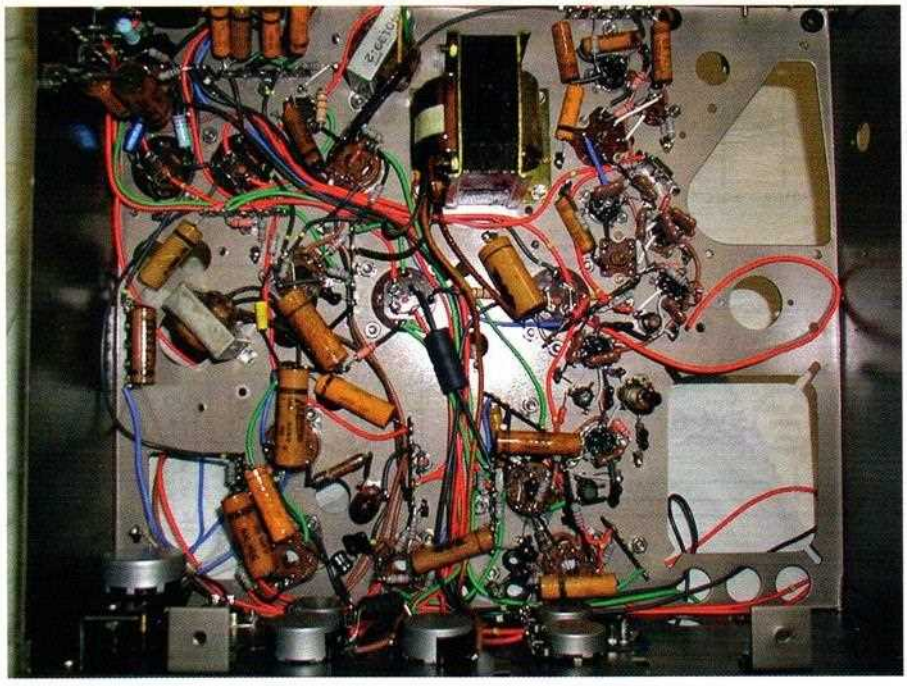
The complete circuit diagram for the RCA 621TS TV set.

Australia's electronics magazine siliconchip.com.au


621TS
V115 6AU6 2ND. SOUND I-F
T108 SOUND DISCR. TRANSF.
V116 6AL5 SOUND DISCR.
R182 100K
R181 100K
V118 6K6-GT AUDIO OUTPUT
T109 AUDIO OUTPUT TRANSF.
C159 .005
C118D 20 MF.
C148 33
C151 56
C152 56
C153 47
R190 5.1
C156 270
C157 .01
C158 .01
C114 1500
C149 .01
R176 470K
R177 22K
R178 1000
C150 1500
V117 6AT6 1ST. AUDIO
C155 .0025
R183 1 MEG. SOUND VOLUME CONTROL
R180 10 MEG.
C154 .0025
R179 330K
R184 470K
R185 1000
+135 V.
+225 V.
-15 V.
TO R173 (H.V. BLEEDER)
R128 500 K BRIGHTNESS CONTROL
R127 220 K
R129 100 K
V102 6AG5 2ND. PIX. I-F
V103 6AG5 3RD. PIX. I-F
V104A 6H6 2ND. DET.
V105 6SN7-GT 1ST. VIDEO AMPL. 2ND. VIDEO AMPL.
C108 270
C112 270
L105 120 MU.H. 4.5 Ω
L102
R114 10K
R116 4700
T101 CATH. TRAP 21.25 MC.
L103
L104 36 MU.H. 2.4 Ω
C160 .05
R119 22K
C115 .05
R121 1 MEG.
R123 39K
L106 180 MU.H. 7.5 Ω
L107 36 MU.H. 2.4 Ω
R124 3300
R125 1000
C118 0.1
C117 0.1
C116C 10 MF.
R126 1000
R112 39
C109 75
C107 1500
R113 1000
C110 100
R115 150
R117 1000
C111 1500
C113 10
R118 4700
R194 1 MEG.
R120 47
R122 1500
+425V.
+7500 V.
TO R171 (FOCUS CONTR)
COATING
GLASS
V113 7DP4 KINESCOPE
R105 2700
R108 10 K PICTURE CONTROL
R109 1000
V107 6SN7-GT VERT. OSC. & DISCH. VERT. OUTPUT
T102 VERT. OSC. TRANSF.
C126 4700
R143 1 MEG.
C129 0.25
R146 2.2 MEG.
T103 VERT. OUTPUT TRANSF.
VERTICAL YOKE 62 Ω TOTAL
R101 560
R151 560
L108
L109
R138 8200
C124 .005
C125 .005
R144 1 MEG. VERTICAL HOLD CONTROL
R140 6.8 MEG.
R139 1.5 MEG.
R141 2.5 MEG. HEIGHT CONTROL
C128C 150 MF.
R147 1000
R148 5000 VERT. LIN. CONTR.
R149 3300
C130 0.1
C131B 10 MF.
R150 1000
C127B 10 MF.
R152 20 C.T. VERTICAL CENTERING CONTROL
R153B 1200
R193 22K
R192 82 K
R154A 50
R154C 9000
R154B 120
ION TRAP MAGNET COIL
L110 32 Ω
L111 3 Ω
R189 56
C116A 40 MF.
C116B 40 MF.
R153A 620
C128A 40 MF.
C132B 1000 MF.
C132A 250 MF.
R166 20 C.T. HORIZONTAL CENTERING CONTROL
TO R128 (BRIGHTNESS CONTROL)
R173 1.8 MEG.
R172 6.8 MEG
R171 5 MEG. FOCUS CONTROL
TO V115 PIN NO. 6 (1ST. ANODE)
V110 1B3-GT/8016 H.V. RECT.
R142 56 K
T105 HOR. OUTPUT & H.V. TRANS.
R187 2.2
R167 470 K
R169 12 MEG.
R168 10 MEG.
R170 12 MEG
C142 500
HORIZ. YOKE 14 Ω TOTAL
L114
L115
C141 56
V109 6B66-G HORIZONTAL OUTPUT
R159 680 K
V111 5V4-G DAMPER
L112 WIDTH CONTROL
L113 36 Ω HOR. LIN. CONTR
R165 5300
500
500
SPEAKER FIELD 62 Ω
C127A 80 MF.
C131A 40 MF.
C128B 40 MF.
V112 5U4-G RECT.
TO KIN.
TO HEATERS
R162 100
R163 18K
R164 15K
C137 0.1
C138 .05
C139 .035
C140 0.1
T106
S101 ON-OFF SW. (ON R183)
C143 .01
C144 .01
J101 INTER-LOCK
117 V. 60 ~ SUPPLY
621TS (7" TABLE) W-93529







Photos 7, 8 & 9: the chassis as it progressed through restoration. All resistors were changed to 2W metal film types, and the wiring cleaned up.

1.5pF neutralisation capacitors in the 6J6-based RF amplifier.

I mainly used metal film resistors throughout. That helps to keep the noise down a little. The valve sockets are NOS (new old stock), including the original push-on shield type for the local oscillator valve. I replaced the push-on shield, identical to the rusted original. I also replaced the rivets and original screws with 4-40 and 6-32 stainless steel screws (to avoid future rusting).

Although I used stainless locking washers, applying varnish to the threads never hurts, so I did.

Restoration well underway

Photos 7-9 show the chassis' progress throughout the restoration. By Photo 9, the underside of the chassis was re-wired and fitted with all-new resistors, wiring and valve sockets. The resistors are now all 2W metal film types, yet the same size as the original ¼W or ½W types.

After replacing the innards, I cleaned the wax off the cardboard shells of the wax paper capacitors and varnished them with marine grade varnish. This way, they look excellent, but the surface is not tacky to touch and won't pick up as much dust as wax does.

I replaced the octal sockets with American mil-spec brown phenolic sockets with wrap-around pins and stainless steel saddles. Similarly, I replaced the 7-pin sockets with American phenolic sockets from Antique Electronic Supply (AES).

AES (USA) supplied all the new capacitors, including the micas, electros and polyesters, several NOS valves for the set, the 300BX power transformer and new tag strips. They always send me excellent valves and parts at competitive prices.

The adjustable IF coils had very rusty spring mounting clips, so I replaced them with new ones, as they are a common part of many NOS coils.

The originals were soldered to the chassis on the top, presumably to prevent capacitive effects from affecting the IF tuning. I simply soldered them to the nearest Earth lugs under the chassis with a short link wire to avoid soldering to the top surface of the chassis.

The new wiring is medical-grade silicone rubber covered hook-up wire, which looks just like old-fashioned

rubber-covered wire, but is extremely heat resistant, and this insulation never melts back near the solder joints (even if the iron is set to 480°C). The wire is pleasant to handle and flexible, but stays where it is put on the whole. It is about 2.5mm outside diameter and has 16 strands.

Once you have used superior wire like this, it is tough to go back to PVC-covered wire or anything else. Silicone covered wire is available from Jaycar, Altronics and RS components.

I stuck to the colour scheme on the wiring diagram where possible. Fabric-covered wire is available, although I suspect it would meet the same fate as the original wire over the next 60 years. The silicone rubber wire will outlast it, I'm sure. Ideally, I want the restoration to look about the same in 50 years.

Photo 10 shows the top of the chassis close to the end of the restoration process.

Mounting the CRT for testing

The 621TS chassis design only allows the CRT to be mounted properly when the chassis is in the cabinet. This is very inconvenient when the chassis is out of the cabinet, so I designed the support shown in Fig.3. It is attached by lengthening the two upper speaker screws and adding two spacers, and it sits on the speaker brackets (see Photo 11).

The screw holes are best marked out after the bracket is in place. The CRT sits on it, and you can strap the CRT to the bracket with a large (industrial-sized) Nylon cable tie with the chassis out of the cabinet. The added timber bracket can stay put when the chassis is re-fitted to the cabinet, and the CRT is mounted in the usual way.

The radius of curvature of the cut-out in the timber is 93.5mm. This is reduced to 90.5mm when the rubber cushion is added to hug the CRT curvature. The bracket geometry ensures the CRT neck is very close to level with the chassis surface. No extra holes need to be drilled to fit it. Photo 12 shows the CRT fitted to the chassis with the assistance of the bracket for testing and adjustment.

Power transformer

Photo 13 includes the original power transformer. I took the copper flux band and covers off it and blasted

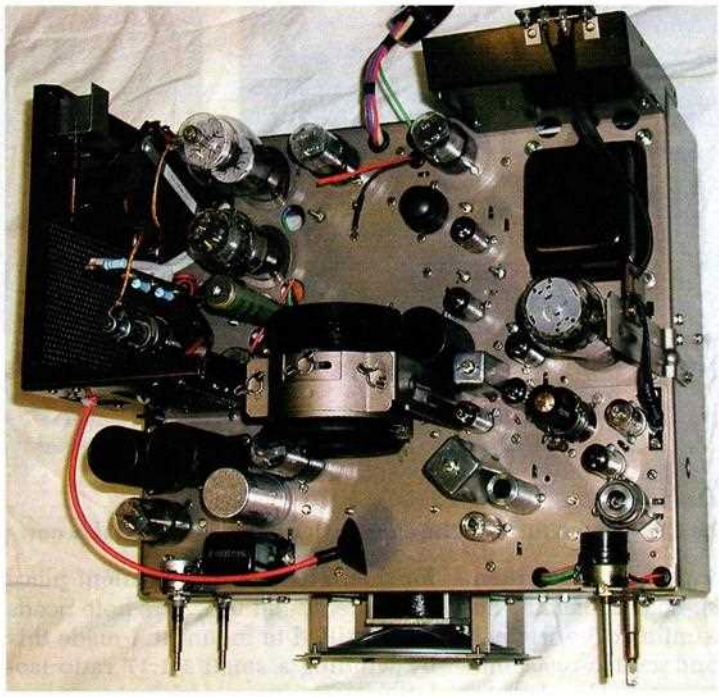


Photo 10: the top of the chassis once nearly finished being restored.

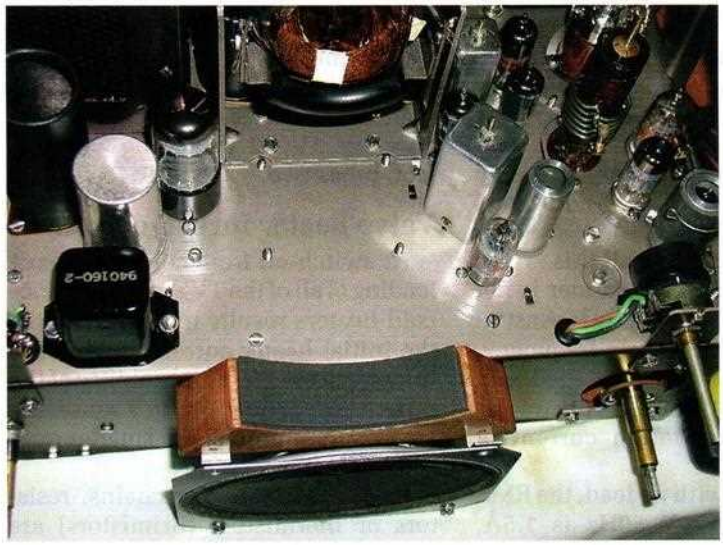


Photo 11: I designed this support to allow the CRT to be mounted when the chassis is out of the cabinet. The support sits on top of the speaker brackets and is shown in greater detail in Fig.3 below.

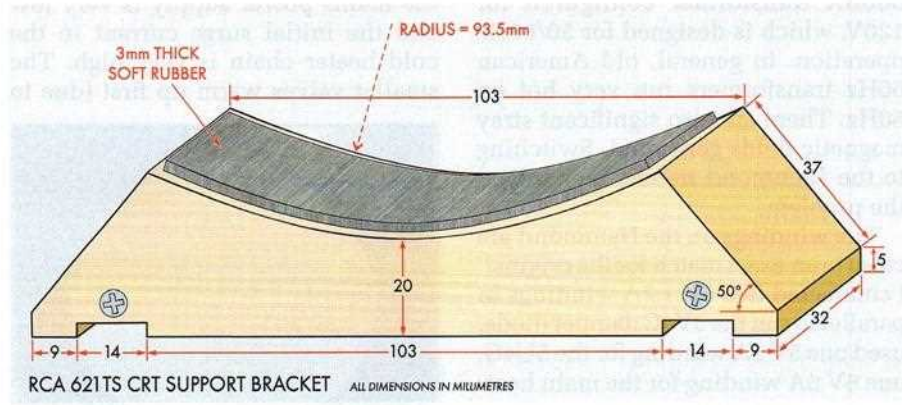


Fig.3: the support bracket helps the neck of the CRT reach close to level with the chassis surface, it's designed so that no extra holes need to be drilled into the chassis to fit it. It is attached by lengthening two screws from the speaker brackets and adding two spacers. The screw holes can be marked out by hand after the bracket is in place.

Photos 12 & 13: the CRT shown fitted to the chassis (left) and the original & new power transformers (right)

the original brackets free of rust, then had them powder-coated black. The finish looks very similar to the original and is corrosion and scratch-resistant.

I then added the restored brackets to a new Hammond 300BX transformer, discarding the Hammond covers as they are pretty different. The two transformers have very close to the same geometry stack, just with the holes placed a little differently. The two wires for the 120V configured primary windings have to exit via an additional hole in the top bracket.

The reason for doing all this is that the original power transformer is not safe to run again, especially in Australia with our 50Hz supply frequency. The transformer has very aged and cracked insulation and draws an excessive magnetisation current at 50Hz.

For example, with no load, the RMS current at 115-120V 50Hz is 1.5A, compared to 47mA for the Hammond 300BX transformer configured for 120V, which is designed for 50/60Hz operation. In general, old American 60Hz transformers run very hot on 50Hz. There are also significant stray magnetic fields generated. Switching to the Hammond transformer solved the problem.

The windings on the Hammond are close to an exact match for the original. I connected two 5V 1.2A windings in parallel to run the 5V4G damper diode, used one 5V 3A winding for the 5U4G, one 6V 6A winding for the main heaters and one 800V centre-tapped winding for the HT supply.

There is only one winding 'missing', a small 6.3V one for the CRT heater, so I added a small auxiliary transformer for that. There is a convenient place to locate it, and only one hole needs to be drilled to mount it. I made this by winding a small 1:1.17 ratio isolating transformer, which gives a separate 6.3V output at 0.6A to provide the CRT heater supply from the power transformer's 6.3V winding.

Note that the data sheet on Hammond's website says the 300BX has only one 5V 1.2A winding when, in fact, it has two.

Valve heater inrush currents

At switch-on from cold, the heavy loading of all of the TV's low-resistance cold heaters results in a slow rise in the initial heater currents due to the limited current handling ability of the power transformer. So, in a sense, the larger valves protect the smaller ones at switch-on.

But in series heater chains, resistors or thermistors (Brimistors) are needed as the internal resistance of the mains power supply is very low and the initial surge current in the cold heater chain is very high. The smaller valves warm up first (due to lower thermal inertia) and more voltage is developed across their heaters without current limiting.

It is interesting to note that the same problem described above will occur within any indirectly heated valve if you connect the heater pins across a power supply of very low internal resistance. The part of the heater close to its internal connections warms up first, as there is less thermal inertia there than the part in contact with the cathode or the weld to the pin connection.

So you will get an initial bright flash from that area of the heater at turn on. In fact, you can get this effect if you unplug nearly all of the large valves in a TV, except for a small one. At switch-on, you'll also get a bright flash, as the large power transformer is, under these circumstances, able to maintain 6.3V across the single small valve's pins without the voltage collapsing under load.

I had to replace the two-turn heater winding for the 1B3 rectifier as the original had degraded insulation. I found some identical geometry wire

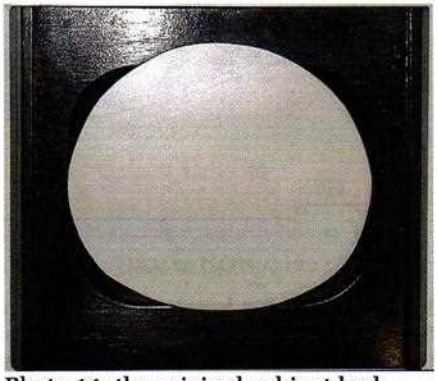


Photo 14: the original cabinet had been enlarged around the CRT.

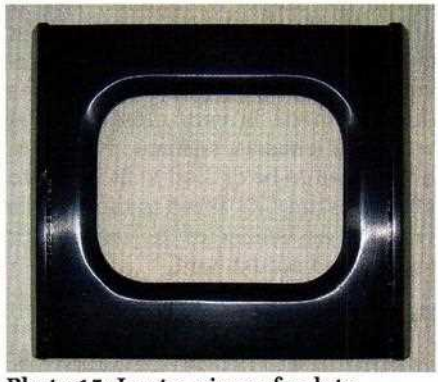


Photo 15: I cut a piece of oak to reproduce the original CRT window.

inside the red sheath of some modern 25kV anode wire.

Also, all of the large Allen Bradley resistors in the focus chain were open-circuit. I replaced them with 10kV-rated Philips focus-grade resistors.

I also replaced the doorknob capacitor with a 1000pF 15kV type (the same physical size as the original 500pF capacitor), allowing for CRTs without external Aquadag. I'm not 100% sure if the original doorknob capacitor is OK; it only reads 375pF, and I've read reports of them failing in the 621TS.

Electrical alignment

I aligned the set according to the manufacturer's instructions but also with the aid of a sweep generator. Scope 1 shows the overall response from the antenna to the video detector.

Screen 1 is an un-retouched image taken via a camcorder on still frame with an RF modulator. The broad grey vertical band at the top is an artefact of the camera's exposure time versus the scanning frame rate of the picture.

Cabinet restoration

One big problem I had with the set was that the cabinet section over the CRT face had been cut away to enlarge the viewable area of the CRT. Perhaps one previous owner wanted a bigger picture! So some timber was missing, as shown in Photo 14. I cut out a square area and glued in some Tasmanian oak to repair this.

I then varnished it and shaped it to match the original design and fit the curved CRT face. Applying varnish initially helps with getting the geometry right as one files the timber away by hand.

Finally, I lacquered it to match the original part and got the result shown in Photo 15. Photo 16 shows the restored cabinet, while the lead photo is the final result.

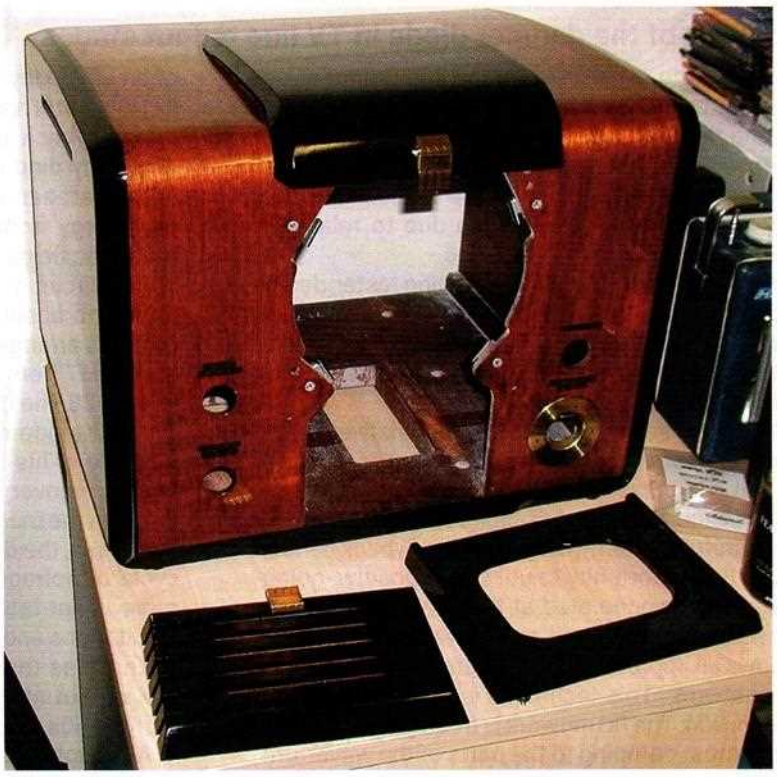


Photo 16: the restored cabinet with the newly made CRT cutout.

Summary

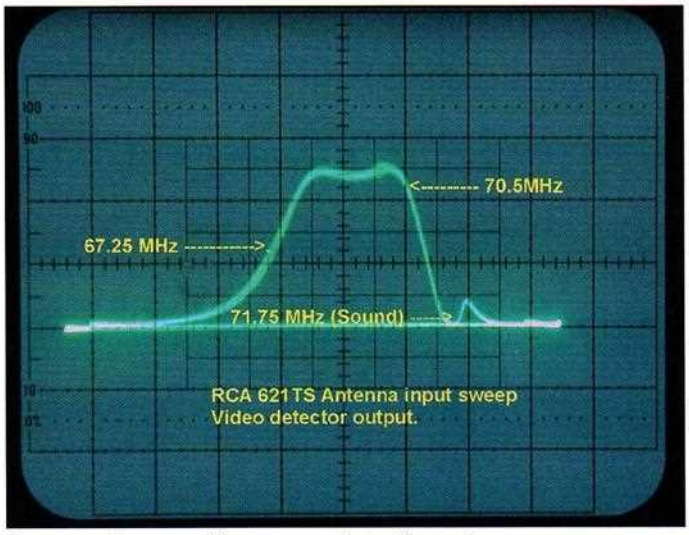
The 621TS is an extraordinary television set, marking a major milestone in commercial TV manufacturing. The entire design is futuristic, and the performance is outstanding for a set put on sale in 1946.

FM sound became the gold standard for television audio after WW2, and the line deflection energy recovery system did too. Any similarly-sized monochrome television set made decades later would not have outperformed it.

The design of the 621TS, except for the absence of the inter-carrier sound system and a horizontal AFC system (both of which would come in later TV designs), set the 'modern standard' of what a monochrome TV would be right up until the mid-1970s.

Finally, from the perspective of industrial design, Mr Vassos created yet another Art Deco masterpiece.

↳ *see panel overleaf*



Scope 1: the overall response from the antenna.

Screen 1: an image of the 621TS screen from a camcorder.

The evolution of the damper diode in TV line output stages

Very basic coupling of the yoke to the line output valve via a transformer is shown in Fig.a. At flyback, the valve is cut off and the magnetic field in the transformer and yoke collapses, resonating due to the self-inductance and distributed capacitance of these structures. The oscillatory voltages and currents are due to relatively undamped oscillations.

These oscillations, visible in the scanning raster, decay away and become damped out when the line output valve is again driven into conduction by the drive voltage. These oscillations must be eliminated for satisfactory raster scanning.

Fig.b shows the same circuit but with resistive damping. Damping occurs over the entire duration of the sawtooth current scanning waveform, on both the positive and negative excursions, ie, it is bidirectional damping.

This is wasteful of energy, lengthens the flyback period, and reduces the opportunity to utilise the positive-going high voltage spikes generated at the line output valve's anode, or via an overwind coil, to generate EHT.

Fig.c shows an improvement to resistive damping using a snubber network. This technique is used in the 1939 HMV Marconi 904. The RC network is frequency-selective, applying the most damping to the parts of the waveform with the highest rates of change.

This reduces the oscillations (shown in red); however, because the flyback period contains high-frequency (Fourier) components, it is also damped. Again, this wastes energy and lengthens the flyback period.

Fig.d shows what might appear to be the introduction of an efficiency diode as in the RCA TRK9 (and TRK 12), but it is not. This circuit has the damper conducting only during flyback and is actually a spike suppressor. A true efficiency diode conducts during the active scan time on the left-hand side of the scanning raster, and recovers energy from the yoke and line output transformer magnetic fields.

The circuit of Fig.d damps the flyback voltage oscillations and absorbs energy when the output valve is cut off. This arrangement can't be used in a system to generate EHT from the flyback voltage spike.

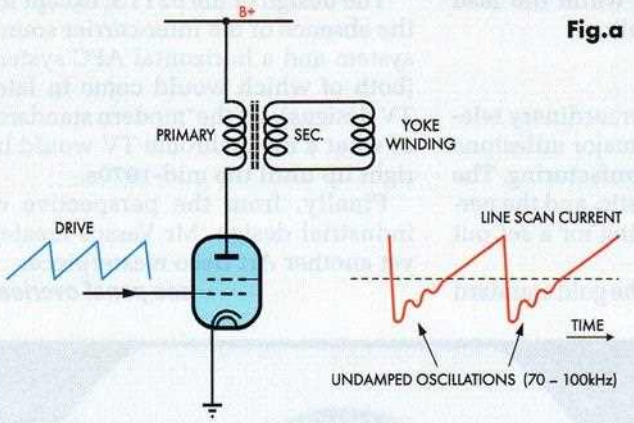
In 1938, the Baird/Bush TV and radio company in the United Kingdom used the circuit shown in Fig.e (on the left side). This is probably one of the first examples of energy recovery scanning.

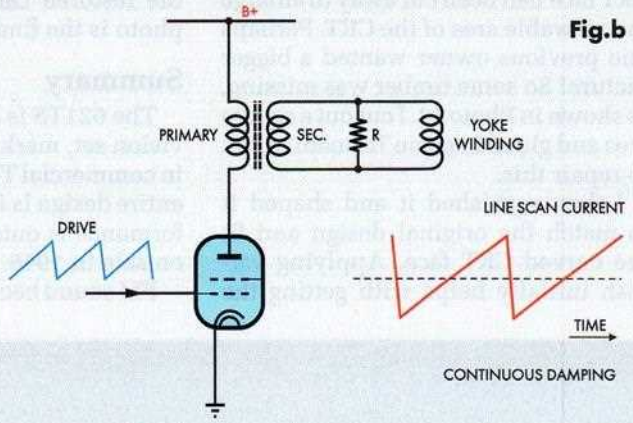
When the magnetic field in the line output transformer collapses, the diode conducts on the first negative half-cycle of voltage on the diode's cathode to produce a more linear rate of change in current. This damps the oscillations and also returns energy to the power supply.

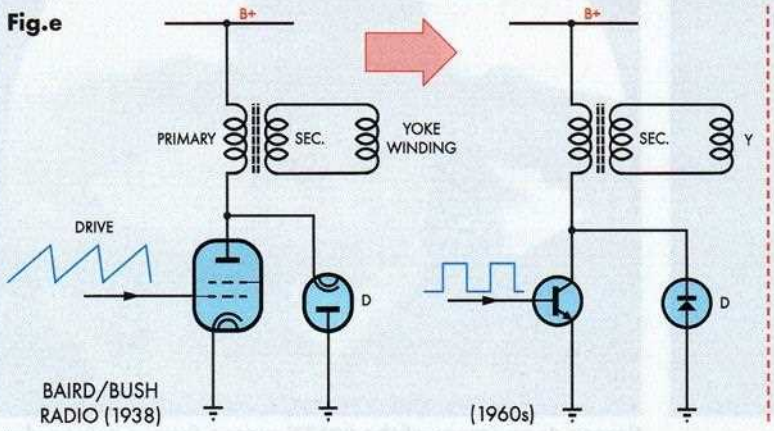
This was the precursor of the typical transistorised line output stage in early transistor televisions in the early 1960s, depicted on the right of Fig.e.

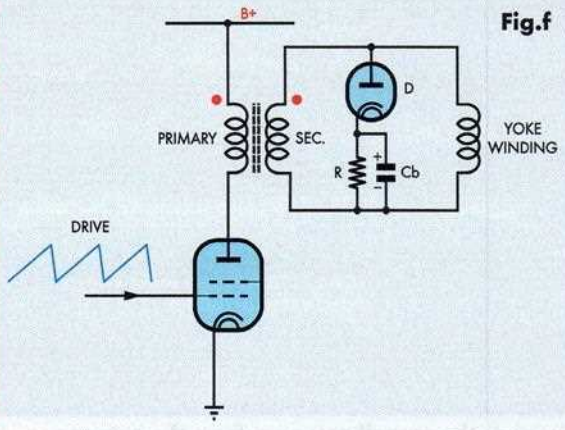
Although the circuit in Fig.f looks a little similar to that in Fig.e, it is actually quite different, with the diode on the transformer secondary side. Observe the transformer polarity.

The current from damping the oscillations charges capacitor Cb and provides energy to load R. Cb charges up and lifts the cathode potential of the damper diode.









So the plate potential has to rise to a higher value to establish conduction.

This helps ensure that the diode is not conducting until the start of active scan time, so there is negligible damping during the flyback period.

This system is "recovering energy" from the magnetic field of the yoke and transformer, which was stored at the end of active horizontal scan time, and delivering it to a load.

This is the basic circuit used in the RCA 621TS, except the voltage generated across the capacitor is in series with the B+ voltage to create what we now know as B+ boost voltage.

When the line output valve is cut off at flyback, the first voltage oscillation half-cycle takes the damper anode negative (cutting it off during flyback). The damper anode has the opposite polarity to the anode of the line output valve. Then when the oscillation brings the voltage positive, the damper conducts.

This damps the oscillations and results in a near-linear scanning current at the left side of the raster, as the magnetic field in the yoke and transformer now collapse in a controlled (damped) linear way toward zero. However, before the current reaches zero, the line output valve is driven into conduction and the process repeats.

The yoke and transformer circuit is equivalent to an inductor with series resistance tuned by parallel distributed capacitance (or a tuning capacitor if fitted). The voltage you see across the transformer or yoke's terminals represents the voltage across the capacitive component, which lags behind the circuit current by 90°.

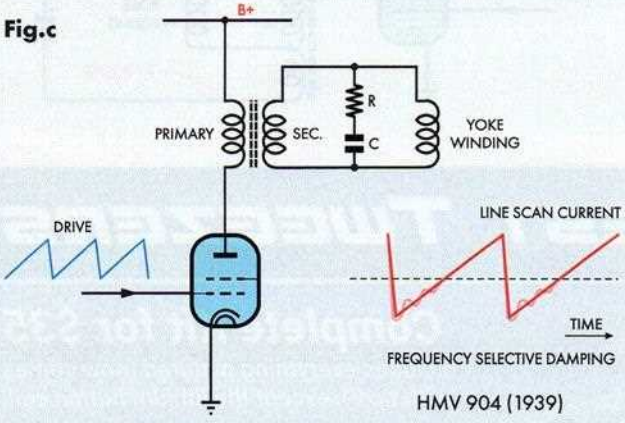
When the output valve is cut off, the circuit current during the flyback period is associated with a negative peak voltage on the damper anode and a positive peak on the line output valve's anode. These peaks occur around the middle of the 10.16µs flyback interval (for the American system). At the time of this peak, the yoke's current is zero (but has its greatest rate of change) and the rate of change of voltage on the diode's anode, although at its peak, is zero.

After that, the secondary voltage returns to zero after flyback, and the current is at a negative maximum with the beam on the left of the raster. As the voltage at the damper anode attempts to oscillate in a positive direction, the damper diode conducts, damping the oscillations and giving a more linear current at the beginning of active scan time on the left side of the raster.

The load resistor can now be replaced with the primary circuit, as shown in Fig.g. RCA used this basic circuit in the 621TS, and this, or a modified version of it, became the 'modern Standard' for line output stage deflection using valves ever since. Cb's negative end can either be returned to ground or B+ as shown, which is at ground from an AC perspective.

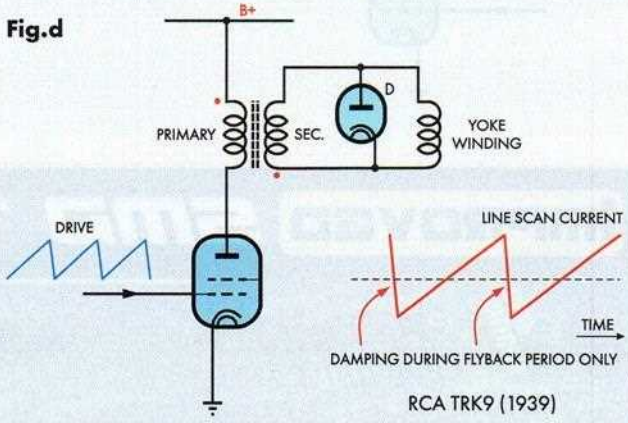
Now the recovered potential energy generated by the magnetic field of the yoke and transformer, which was provided by the primary circuit at the end of the scan (right side of the raster), is used to generate a boost voltage to help supply the primary circuit. This gives a higher primary supply potential, the B+ Boost voltage, which helps attain the required picture width from a lower-voltage B+ supply.

Fig.c



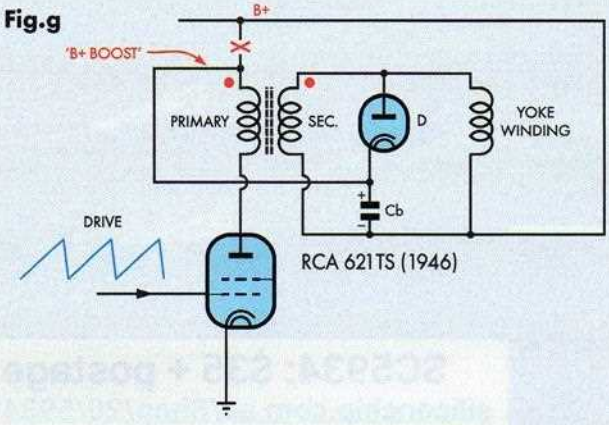
HMV 904 (1939)

Fig.d



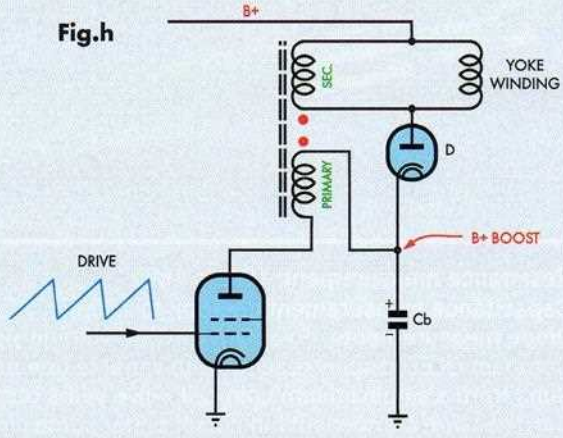
RCA TRK9 (1939)

Fig.g



RCA 621TS (1946)

Fig.h



As is always the case, no additional energy is created that was not already supplied by the power supply in the first place.

The circuit is simply more efficient because overall, the damped current is not wasted as heat, which it is in all cases of resistive damping.

Moving on the Fig.h, we can see what happens if we redraw Fig.g circuit with Cb connected to ground. This circuit, as deployed in the 621TS with slight modifications, is the basis for modern valve line scanning.

At switch-on, a direct current flows via the secondary winding and the damper diode to charge Cb to B+ potential and to initially supply the B+ to the primary circuit. During operation, the voltage across Cb charges to B+ Boost. Therefore, Cb needs to be rated to handle this higher voltage.

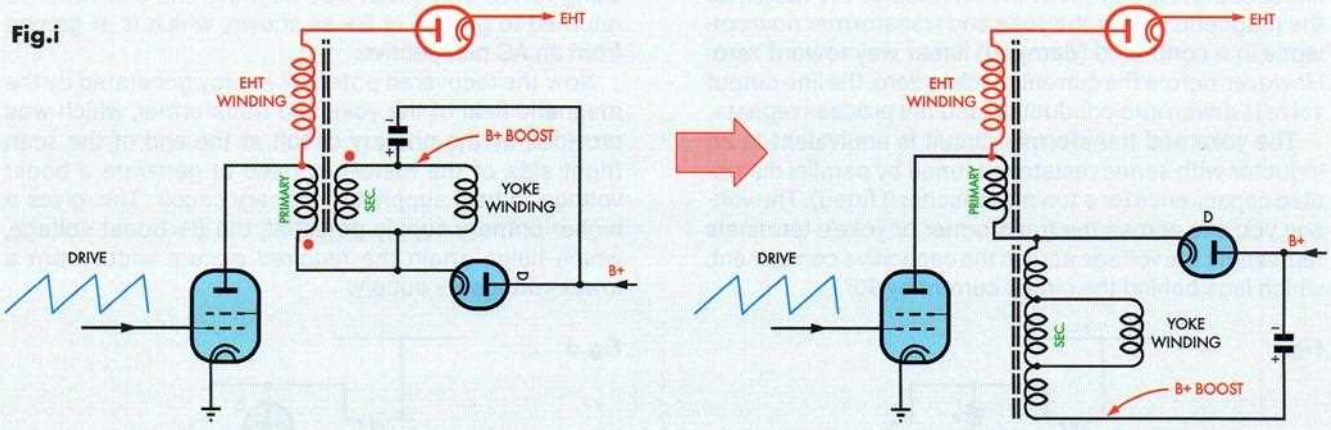
This circuit is inconvenient because the transformer cannot be configured as an auto-transformer. But it is a minor modification to introduce B+ directly at the anode of the damper diode. Then, the circuit comprising the secondary, damper diode and Cb can be rotated to create the circuit of Fig.i.

This circuit has the advantage that the Cb only needs to be rated to handle the Boost component of the B+ Boost voltage, rather than the total amount. Also, the primary and secondary can be one tapped winding, with the yoke coupled across any part of it, in an efficient autotransformer configuration. Admiral used this basic configuration in the early 1950s, for example, in their series 23 chassis.

By the time that efficient energy recovery line output stages arrived, it had become the custom, as it is in the 621TS, to derive the EHT from an over-wind linked to the plate circuit of the line output valve shown in red in Fig.i. The heater supply for this EHT diode was derived from a small number of well-insulated turns on the output transformer.

Other variations of damper diode circuits from the post-war period include a triode pair used as a controlled damper diode, which gives additional control over the linearity of the sawtooth scanning current. SC

Fig.i



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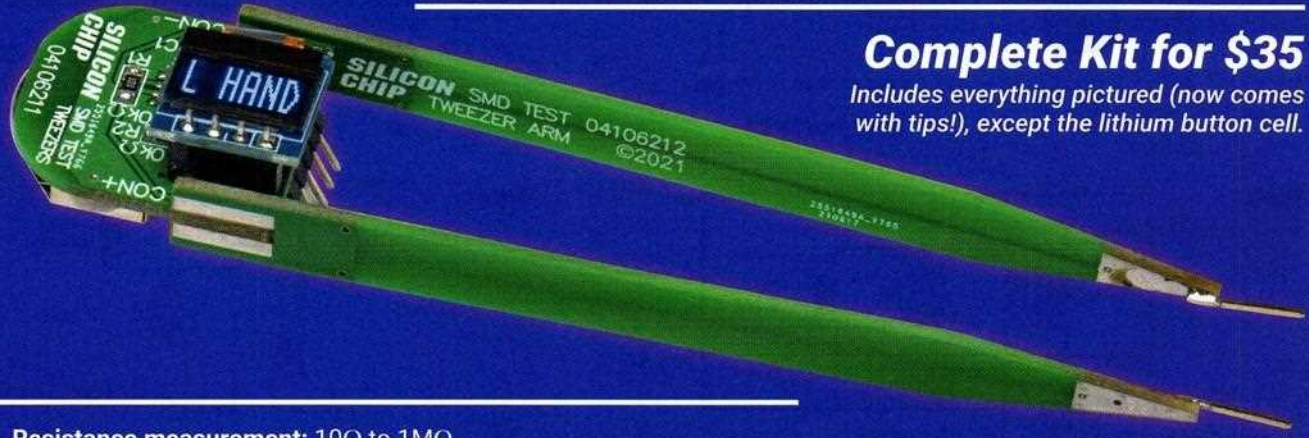

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Help needed installing Microchip software

I read Tim Blythman's article on the new range of PICs & AVRs from Microchip (October 2022; siliconchip.au/Article/15505) and decided to download the MPLAB X IDE. I am finding it impossible to achieve registration and thus use the software.

How much does it cost, and where can I purchase such software and a suitable programming interface board between my HP laptop and the Microchip devices? I have used the PICAXE range of microcontrollers and Arduinos, but I am always looking for an alternative to the PICAXE platform. (P. H., Gunnedah, NSW)

● We have never had to register MPLAB X IDE to use it; it is free software. Version 6.00 is the latest version and we have been using it for a few months now, so we don't think that has changed lately.

Registering and paying for the Pro versions of the XC8/XC16/XC32 compilers is possible, but that is only necessary if you wish to use the non-free versions. The free versions are pretty good anyway; certainly good enough to get you started.

Check that you are using version 6.00 of the IDE (www.microchip.com/en-us/tools-resources/develop/mplab-x-ide). At what stage of the installation are you being asked to register? If you send us a screenshot, we can provide more help.

If you have the January 2021 issue, which includes the article "How to use the MPLAB X Development Environment", starting on page 48, you could refer to the screenshots to guide you through the installation steps.

As for a programmer, you can purchase a PICkit 4 or Snap programmer from a range of sources such as Digi-Key, Mouser, element14 or direct from Microchip: www.microchip.com/en-us/development-tool/PG164140

GPS Clock 'USB device not recognised'

I assembled the GPS Analog Clock Driver (September 2022; siliconchip.au/Article/15466) as per your instructions. I managed to remove a bridge I'd made between the pins of IC3 but did not see the bridge between pins 1 & 2 on CON4 until later. On installing the two AA cells, I was rewarded with two winks from the LED.

When I plugged the USB cable into my Windows 10 PC, I got three winks from the LED – but Windows told me, "USB device not recognised". That is when I went back and discovered the solder bridge on the USB socket.

With the USB socket fixed, I tried again and got the same message. I have tried four different USB cables and three different USB ports. I have again gone over all the wiring with a 40x loupe and can't fault it. Could I have killed a chip, or have I missed something else? (R. W., King Creek, NSW)

● Geoff Graham responds: It sounds like you have tried everything.

"USB device not recognised" is Windows universal message when it detects something on the USB D+ and D- signal lines, but it cannot establish communications. The microcontroller seems to be working as it detects the +5V on the USB connector and goes into configuration mode (three flashes on the LED). So it is probably something between the microcontroller and your PC.

It is very doubtful that you have damaged the microcontroller. I would:

- Recheck the soldering on the USB socket very carefully; this is usually the problem.

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Difficulty measuring the resistance of NTC thermistors

Can you explain why I get three different readings when measuring an NPO [sic] thermistor resistance at room temperature with three different multimeters?

I get a reading of around 6kΩ using a Micronta multimeter, 3kΩ using a Tenma multimeter and 2kΩ when using a cheap, unbranded multimeter (miniature black case with a 12V battery).

Supplying the thermistor with a constant current of 0.27mA, all three multimeters measured the same voltage across the thermistor, giving a calculated resistance of 2.05kΩ. (N. S., via email)

● We suspect that the thermistor is an NTC type rather than "NPO", and its resistance falls with temperature; NTC stands for negative temperature coefficient. The thermistor is probably a small bead type giving a nominal 10kΩ at 25°C.

The lower and varying resistance readings by your multimeters would be due to the heating caused by dissipation in the thermistor from the test current, raising the temperature of the thermistor and hence lowering the resistance. The readings likely vary due to differing test currents, resulting in the thermistor being measured at different temperatures.

The fact that the calculated resistance reading is the same for all multimeters when using a fixed current pretty much confirms this theory. Consider that 0.27mA through 2.05kΩ is 150mW dissipation ($0.27mA^2 \times 2.05k\Omega$), which would be enough to warm up a small bead-type thermistor significantly.

If you want to measure its true 'cold' resistance, we suggest using a much lower test current, like 10µA. That should result in 1mW dissipation, not enough to heat it significantly, and should give a reading close to 100mV across the thermistor if it's a nominally 10kΩ type (10µA x 10kΩ = 100mV).

• Recheck your cables and PC USB ports. I know you have done that, but this is the second most common problem.

• Check the continuity of all USB connector pins to the microcontroller's pins.

• Go into Device Manager in Windows and (if possible) disable the entry listed as "Unrecognised USB device".

• Check that you have at least +3V as VCC for the microcontroller.

Also, try this:

1. Insert the batteries into the clock.
2. Observe two flashes on the LED.
3. Then plug the USB into your computer.
4. Observe three flashes on the LED
5. You should hear the USB connect sound from your PC, and Windows should show a new COM port.

GPS-synchronised Clock is losing time

I have built the GPS Analog Clock Driver (September 2022) from your SC6472 kit (v1.1). After installing it, the clock is lagging horrendously (approximately 10 minutes every hour). I have reverted the changes, and the clock works well with the original mechanism.

I wonder if the problem lies with the inductor, as it differs from what is shown on page 62 of the September 2022 issue. It is also considerably smaller, and I had to solder a bridge to be able to fix it to the board. Could you please advise? (O. M., Willetton, WA)

● Geoff Graham responds: Your problem is not due to the size of the inductor. Due to a mix-up with part numbers, you received a physically smaller inductor, but it has the correct value and will work just as well.

There are a few reasons why you could be experiencing such a large timekeeping error. The most probable is that you have a problem with the movement; for example, some debris has fallen into the gears. I know that you reverted to the original controller and it worked, but you might have cleared the problem while making that change.

Other (less probable) things to check are:

• Did you properly isolate the clock's controller chip by cutting the PCB track leading to it?

• Do you have the correct value padding capacitors (22pF) on the crystal? Presumably you do as they were supplied in the kit, but it's worth checking them if you have a suitable test instrument.

• Is the crystal working correctly at the right frequency? An oscilloscope would be handy here.

• Are the batteries fresh (ie, approximately 1.5V each)?

• Recheck your soldering carefully, joint by joint and recheck the value of each component.

Many constructors have it running fine (hundreds by this stage, we reckon), so there must be something unique that has happened in your case. The problem will be in finding exactly what it is.

GPS-Synchronised Clock not restarting

The GPS-Synchronised Clock (September 2022) is a great little project – the first I've built in many years! But I have a problem: I cannot do a full restart. I dropped the clock and had to make some repairs, but even though I've taken the batteries out for several hours, the clock won't go into restart mode. Any ideas? (K. M., Narara, NSW)

● Geoff Graham responds: That is a strange fault. By "cannot do a full restart", I presume that you mean that when you reinsert the batteries, the clock immediately starts running (ie, driving the hands).

If this is the case, I suggest you insert the batteries, then plug it into a USB host. That should force it into configuration mode. Then, when you unplug it, the USB firmware will do a complete reboot and start from scratch. If that doesn't work, it indicates a physical fault of some sort, probably with the USB connector.

A competitor to the Raspberry Pi Pico

Will the Ox64 module (siliconchip.au/link/abhq) fit the VGA PicoMite boards? Is there any chance this new board will be compatible with the Pico? The new boards should be very good with lots of RAM and flash. It was interesting to learn that the Pico only has USB 1.1; I did not know that. (P. B., Turramurra, NSW)

● It's relatively uncommon for microcontrollers to have USB High Speed support; many are limited to USB 12Mbps 'Full Speed', like the Raspberry Pi Pico.

Regarding your questions, Geoff Graham responds: We haven't tested whether that board will fit. If you're lucky, it might. But there is no chance it will be compatible as it uses

completely different technology.

There are so many different processors and boards being made that it would be impossible to make the firmware run on all of them, so we pick one or two of the most popular, then make sure that the BASIC interpreter works perfectly on them.

Inductors for AM-FM DDS Signal Generator

I need help finding the Coilcraft 1206CS-121XJEC 120nH chip inductor specified for the May 2022 AM/FM DDS Signal Generator (siliconchip.au/Article/15306). It does not appear to exist on either the Coilcraft or Tricomponents sites. (J. S., Avondale, Qld)

● You can find it on Coilcraft's website at siliconchip.au/link/abhl

That part is not particularly critical; many manufacturers have 120nH chip inductors that could be used. According to the article, on page 45 under "Component Selection", the inductors are available from element14. They don't have the XJEC version, but they do have the XGLC and XJLC versions; see siliconchip.au/link/abhm

The only differences are in tolerance (G = 2%, J = 5%) and termination (halogen-free vs not halogen-free), which won't matter.

Using solid-state switching for an SMPS

I've just installed some LED lighting in a room and am using Cree X-LEDs driven by MEAN WELL ELG-75-C350B switch mode power supplies (www.farnell.com/datasheets/2830610.pdf). It's working fine, but I intend to turn the power supplies on and off and control the dimming using a microcontroller.

I'm looking for solid-state relays (SSRs) to provide the on/off function; it seems I need a solid-state relay that can supply 50A for half a second or so, then handle a minimum load current of 400mA. From what I can ascertain from product data sheets, low working current SSRs can't handle the inrush current, and the SSRs that can handle the inrush current have too high a minimum working current.

Is there a product or solution to turning these switch-mode power supplies on and off via an output from a microcontroller? (T. B., Bumberrah, Vic)

● You should be able to switch the supply on using one of the smaller SSRs by including an NTC thermistor in series with the SSR switching device. This introduces a resistance that will limit the startup current. The SL32 10015 NTC thermistors we sell in our Online Shop should work:

siliconchip.au/Shop/7/2755

The minimum current requirement could also be solved by including a resistor across the load to increase the minimum current, although that would be wasteful. Alternatively, include a relay contact that bypasses the SSR (or use a relay to do the switching as they have negligible minimum load requirement).

Finding Serviceman's Log column

Sometime this year, I read a Serviceman's Log article that referred to a device that would not start up. It was a faulty flip-flop chip triggered by the "Power" button. Now I cannot find it. I have all the relevant back issues here;

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can someone point me to the particular article? I have tried scanning every issue from 2022, so I think I might have been browsing an older issue. (B. W., Gowrie, NSW)

● The Word Search feature on our website is helpful for tracking this sort of thing down. We tried Word Searches on "flip flop", "flip-flop" and "flipflop" only in Serviceman columns. Only two issues popped up since 2010: January 2017 and September 2018.

We think the one you're referring to is on pages 47 & 48 of the January 2017 issue. The word search page can be found at: siliconchip.au/Articles/WordSearch

Replacing the Altronics R2000 motorised pot

I want to build the Projector Speed Controller (April 2011; siliconchip.au/Article/966), which specifies an Altronics Cat R2000 Alpha dual gang 20kΩ motorised potentiometer. That part is no longer available from Altronics. Do you have any recommendations for replacements? (K. T., New Zealand)

● Suitable motorised potentiometers are available from eBay at reasonable prices. The actual potentiometer and its value are unimportant as that is not used; just the motor mechanism is used.

So any value, log or linear, single or double gang Alpha or Alps branded motorised potentiometer will be suitable. For example, see:

- siliconchip.au/link/abgh
- siliconchip.au/link/abgi

Big Digit 12/24 Hour Clock saga

My 12/24 Big Digit Clock (March 2001; siliconchip.au/Article/4235) performed exceptionally until I tried to change the speed setting slightly. After pressing switches 1 & 2 to come back from adjustment mode to clock display mode, the display went back into adjustment mode after briefly displaying the clock.

I tracked this down to one of the backup batteries having moved down under one of the large display chip pins and shorting, causing all four large display decimal points to come on and nothing else. I fixed this, and the clock again performed flawlessly.

Then I saw that good-quality double-sided PCBs were available from Silicon Chip. My clock was built using much lower-quality PCBs, so I purchased both boards and proceeded to rebuild the clock using most of the components from the old PCBs with some new batteries, IC sockets and header pins, plus ICs 2 & 3 (they were soldered to the board).

Since the rebuild, only LED displays 5 & 6 turn on, and they are not showing the correct segments for the numbers. I can select adjustment mode, the "Variant" and "Standard" modes and the 12hr/24hr modes. The seconds advance (albeit incorrectly displayed), and the "AD", "U" and "S" are shown in adjustment modes.

LED displays 1, 2, 3 & 4 do not light up in either clock or adjustment modes. Displays 5 and 6 have the same segment errors as the numbers count.

I have replaced the eight BC328 transistors, IC1, IC2 and IC3, plus I spent many hours checking for shorts, opens and any other things I thought might cause these problems.

This has been one of the best projects I've ever built, but I am now totally exhausted and somewhat disappointed with myself for trying to improve my seventeen-year-old clock that had been constructed on old-style tan-coloured single-sided PCB. As I have run out of ideas, can I send you the clock to see if you can figure out the problem(s)? (R. H., Dee Why, NSW)

● We can't troubleshoot every project when constructors run into trouble, but as it sounded like R. H. had tried everything, we agreed to take a look. Thankfully, we got it working again after fixing a few faults.

The dimming did not work because there was a 470Ω resistor in parallel with the LDR instead of the required 470kΩ resistor. The incorrect segments lighting was cured by reprogramming the microcontroller.

The LED brightness was significantly different between the smaller seconds displays and the larger displays, probably because the smaller displays were much more efficient than those used in the original project from over 20 years ago. We altered the segment drive resistors for the smaller displays to 820Ω instead of the original 220Ω to get them to match.

The decimal points on the larger displays were also brighter, so we used 820Ω for them as well instead of the original 180Ω resistor. The larger displays used seem to use a single LED for the decimal point rather than the two in series used for the original displays in the 2001 prototype.

We also noted a slight difference in brightness between display 3 and displays 1, 2 & 4. This is due to slightly different LED efficiencies between the displays. Not much can be done about that except for finding a set of four LED displays with better-matched brightnesses.

If you want the displays to be brighter overall, you can use a 15V plugpack to power the clock.

Appliance timer and soft starter wanted

These days households have numerous chargers that are typically plugged in and left turned on. This has always concerned me as the charger or device under charge could develop a fault and catch fire. A good solution to this problem would be to use a timer that automatically disconnects the mains supply after a preset duration.

The timer would have many applications: power tool chargers; laptop, tablet & mobile phone chargers; cordless vacuum cleaner chargers; soldering irons; or even Christmas lights.

The timer must have the ability to set a range of different durations using a rotary switch that is easily accessible. It should have a manual start button and an indicator to show that the output is on. The timer should only draw power from the mains while it is active.

Another idea is to add a slave output to the two soft starters for appliances and power tools described in April and July 2012, respectively. This could be used for a shop vac that runs to collect dust from the power tool in use. The output for the shop vac should turn on immediately when any current is drawn by the power tool and remain running for a few seconds after the power tool is turned off.

Maybe the soft starter for power tools design could be used as the basis of a new project by adding a slave relay to power a shop-vac. It is important to consider the total power used by the power tool and the shop vac. (J. L., Stafford, Qld)

● We have published similar projects in the past. We are currently working

continued on page 112

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on many projects, so we can't start on anything new, but we might consider updating these older projects at some point.

We published a Universal Safety Timer for Appliances (August 1990; siliconchip.au/Article/6923), although admittedly, that design could do with an update. For example, it uses a Triac as the switching device, so it would not handle capacitive loads very well. It also draws a little standby power.

We have also published numerous soldering iron timer designs in Circuit Notebook, including one in July 2020 (siliconchip.au/Article/14510) along with March 2016, January 2007 and October 1992.

Regarding the Soft Starter for Power Tools with a switched slave output, we published two master/slave mains power projects which could have soft starting incorporated. They are the PowerUp Master/Slave Power Switch (July 2003; siliconchip.au/Article/3905) and the Circuit Notebook entry titled "Anto-sensing master/slave power control" (October 2010; siliconchip.au/Article/321).

Given the age of these designs, it is probably worthwhile for us to revisit these ideas when we get a chance.

Wanted: comprehensive portable audio test set

I have recently been helping my son install subwoofers in his friends' cars, along with a couple of head units. They pick up an amplifier, speakers and subwoofer pretty cheaply second-hand from online marketplaces.

We've found that sometimes it doesn't work, so you need some way of testing each segment, which has proven cumbersome. Has there been a project or two that would make a set of test tools to work through the pieces? Should we make one? For instance, the following things need to be checked:

Head-unit: are the speaker outputs working? Are the line-level outputs working? Is the line-level output LF only, or full-frequency? What voltage level/volume is being produced?

Amplifier: what is the power supply voltage? Does it fluctuate under load? Does the ignition key switch the power, or is it a direct battery feed? What is the output level and what is the signal frequency range? It would be helpful to be able to feed in a line-level signal and provide a frequency sweep.

Control wire: did we find the right one? When does it switch?

Speakers: an impedance tester would be helpful, along with a way to determine the phasing of dual-coil drivers (they are relatively rare).

Cables: check for resistance and continuity.

Some of these tests do fit under the basic multimeter regime. Some might be as simple as an audio cable from a smartphone with the correct impedance/level. (L. C., Donvale, Vic)

● There is no easy way to make up a universal test set for what you want. However, you can use separate items such as a multimeter, oscillator and load resistances.

A multimeter can be sufficient for most of the tests required, especially if it is suitable for measuring AC voltages up to 1kHz or more.

A signal generator would be helpful to provide a source for the amplifiers under test. We've published a few useful portable oscillators:

- Shirt-pocket, Crystal-locked Audio DDS Oscillator (September 2020; siliconchip.au/Article/14563)
- Roadies' Test Oscillator (June 2020; siliconchip.au/Article/14466)
- Digital Audio Signal Generator (March-May 2010; siliconchip.au/Series/1)

Both the Shirt-pocket Oscillator and Digital Audio Signal Generator would be helpful for testing subwoofers as they have adjustable frequencies. Alternatively, a low-cost commercial audio oscillator could be used.

A load for the amplifier can be made using a heatsink and power resistors. element14 and RS Components both sell high-power resistors. You can connect them in series or parallel to achieve the required resistance and power rating(s). element14 also sells 100W-rated 4Ω & 8Ω chassis-mount resistors (Cat Nos 2925455 and 2925462). SC

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Errata and Next Issue

WiFi DC Electronic Load, September & October 2022: *(1) REG1 is shown reversed on the main Load PCB silkscreening and in Fig.10. Fit it the other way around, as shown in the photo on page 91 of the October 2022 issue.*

(2) a design error on the main Load PCB means that the SDA line (pin 5 on the CONTROL header, CON1) is likely to be shorted to GND due to a GND via placed too close to that track. The via is just above and to the left of IC5 (labelled "DAC" on the PCB). Run a sharp knife between the GND fill and the SDA track to clear the short, or drill out the top side of that via with a small (eg, 2mm) drill bit.

(3) the sole 240Ω resistor on the main Load board should be 470Ω, to match the source impedance of pin 1 of IC3 (1kΩ || 1kΩ). If built with the 240Ω resistor, the resulting error will be minimal and likely cancelled out during calibration.

(4) IC3 & IC4 were incorrectly listed as the INA180B4 type (gain = 200) in the parts list. They must be the B1 type (gain = 20) for correct operation.

Next Issue: *the January 2022 issue is due on sale in newsagents by Thursday, December 29th. Expect postal delivery of subscription copies in Australia between December 28th and January 13th.*

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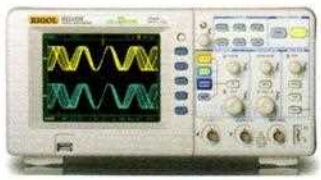

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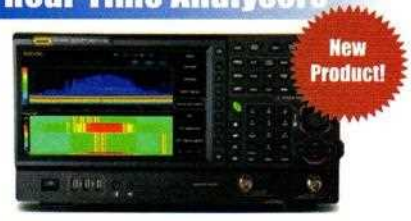

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